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JFETs as electronically controlled resistors

Audio Out

Using audio transformers

KickStart

Low-voltage op amps

Make it with Micromite

Building GPS into PicoMite systems

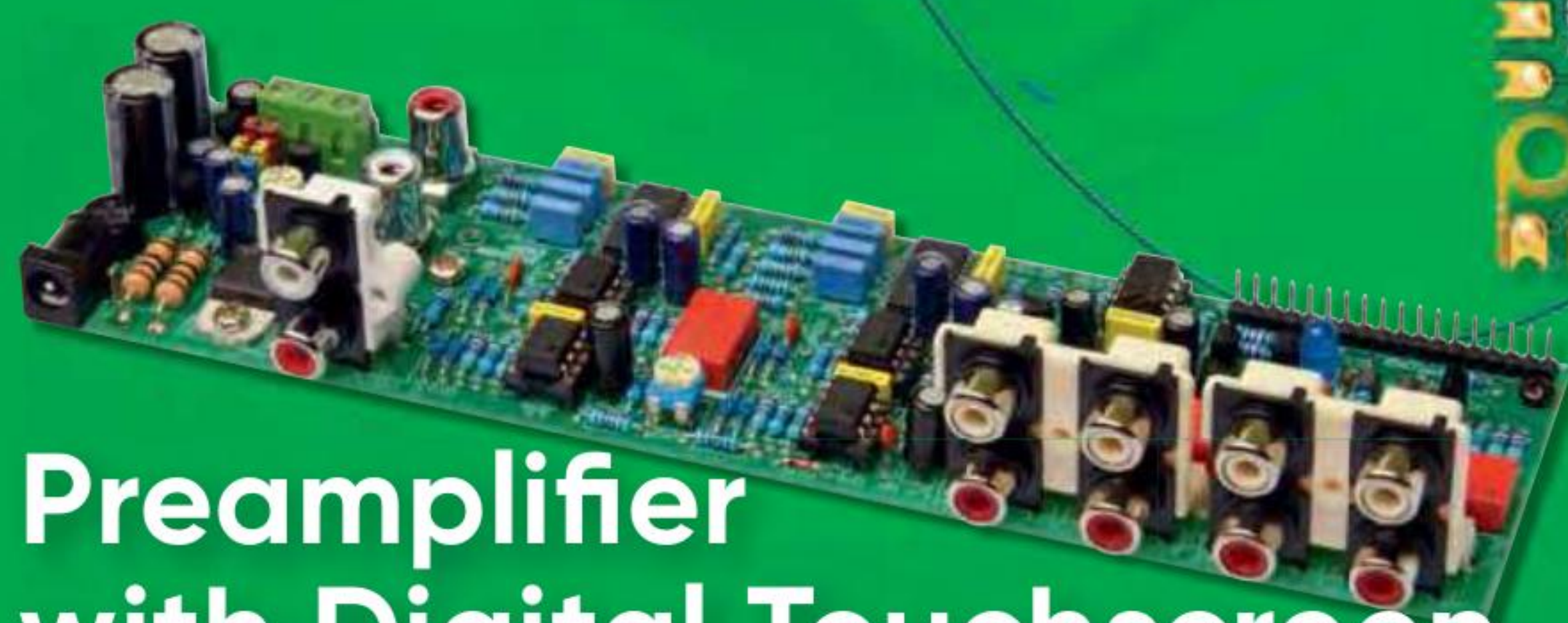


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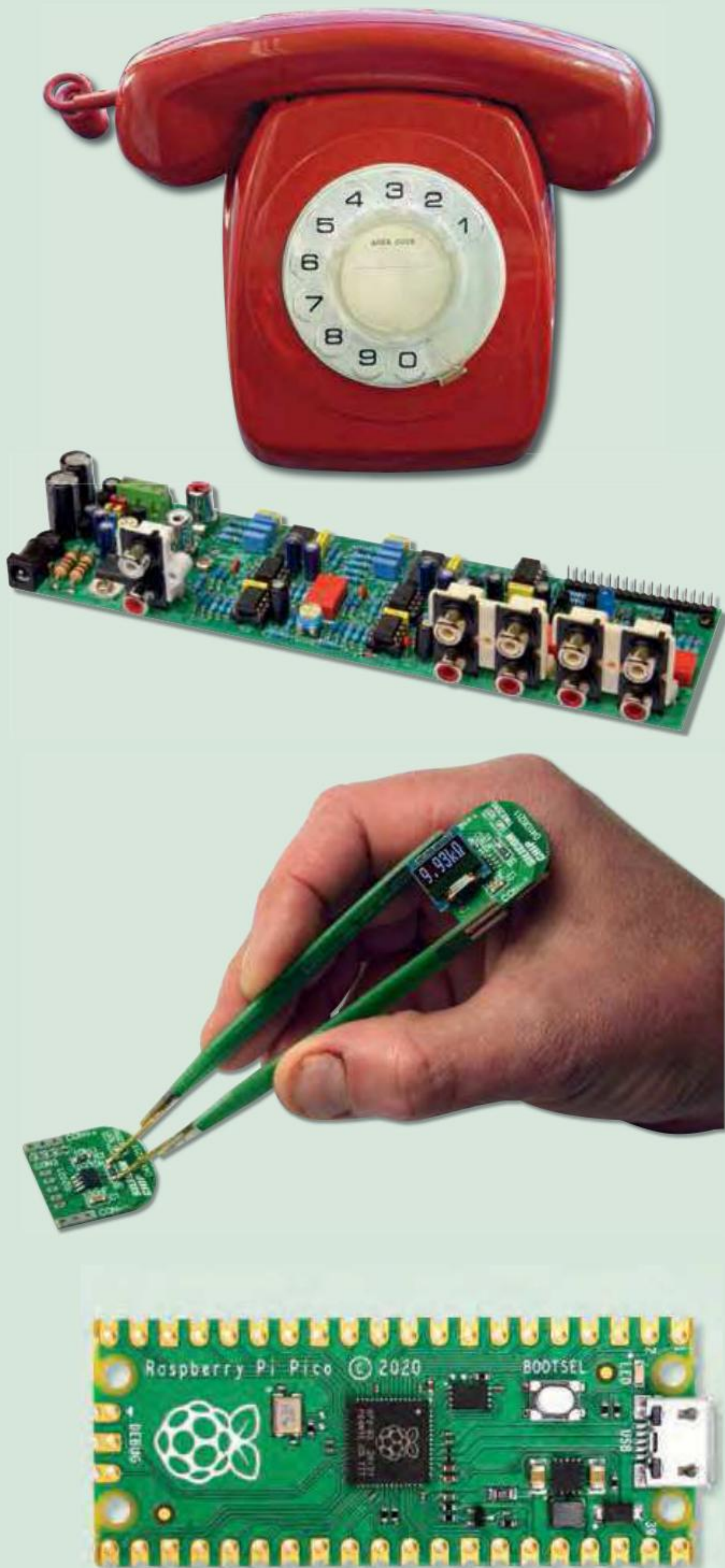
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The November 2022 issue of *Practical Electronics* will be published on Thursday, 6 October 2022 – see page 72.

Projects and Circuits

SMD Test Tweezers by Tim Blythman 16
This clever little device can measure the values of SMD resistors and capacitors, plus show diode and LED orientations and measure their forward voltages.

Tele-com by Greig Sheridan and Ross Herbert 22
Do you have a classic Bakelite phone with a real bell that generates a fantastic ring sound? Now you can hear it again and speak to someone at the other end!

Touchscreen and Remote Digital Preamp with Tone Controls – Part 2 33
by Nicholas Vinen and Tim Blythman
We introduced our new Digital Preamplifier last month. Now we'll go through the construction and testing procedures.

Self-Contained 3.8GHz Digital Attenuator by Jim Rowe 38
This digitally programmable RF attenuator module with a built-in microcontroller can attenuate RF signals from 1MHz to 3.8GHz by 0-31dB in 1dB steps.

Series, Features and Columns

Techno Talk by Mark Nelson 8
Forget leaves on the line!

The Fox Report by Barry Fox 10
A farcical system

Net Work by Alan Winstanley 12
A round-up of topical technological issues and trends from the UK and around the world – from whole-home mesh wireless systems to the latest email clients.

Circuit Surgery by Ian Bell 41
Electronically controlled resistance – Part 2

Make it with Micromite by Phil Boyce 46
Part 40: Simple PicoMite GPS tracker

Max's Cool Beans by Max The Magnificent 50
Flashing LEDs and other engineering temptations – Part 32

Audio Out by Jake Rothman 54
Transformers in audio – Part 3

KickStart by Mike Tooley 58
Part 10: Getting to grips with low-power operational amplifiers

Electronic Building Blocks by Julian Edgar 64
Selecting and Using Actuators – Part 1

Regulars and Services

Wireless for the Warrior 2

Subscribe to Practical Electronics and save money 4

NEW! Practical Electronics back issues DOWNLOADS – 2021 now available! 6

Reader services – Editorial and Advertising Departments 7

Editorial 7
Ring, ring!... SMD tweezers... Please!

Exclusive Microchip reader offer 9
Win a Microchip MPLAB Snap In-Circuit Debugger

PE Teach-In 9 21

PE Teach-In 8 63

Practical Electronics PCB Service 70
PCBs for Practical Electronics projects

Classified ads and Advertiser index 71

Next month! – highlights of our next issue of Practical Electronics 72

WIRELESS FOR THE WARRIOR

by LOUIS MEULSTEE

THE DEFINITIVE TECHNICAL HISTORY OF RADIO COMMUNICATION EQUIPMENT IN THE BRITISH ARMY

The *Wireless for the Warrior* books are a source of reference for the history and development of radio communication equipment used by the British Army from the very early days of wireless up to the 1960s.

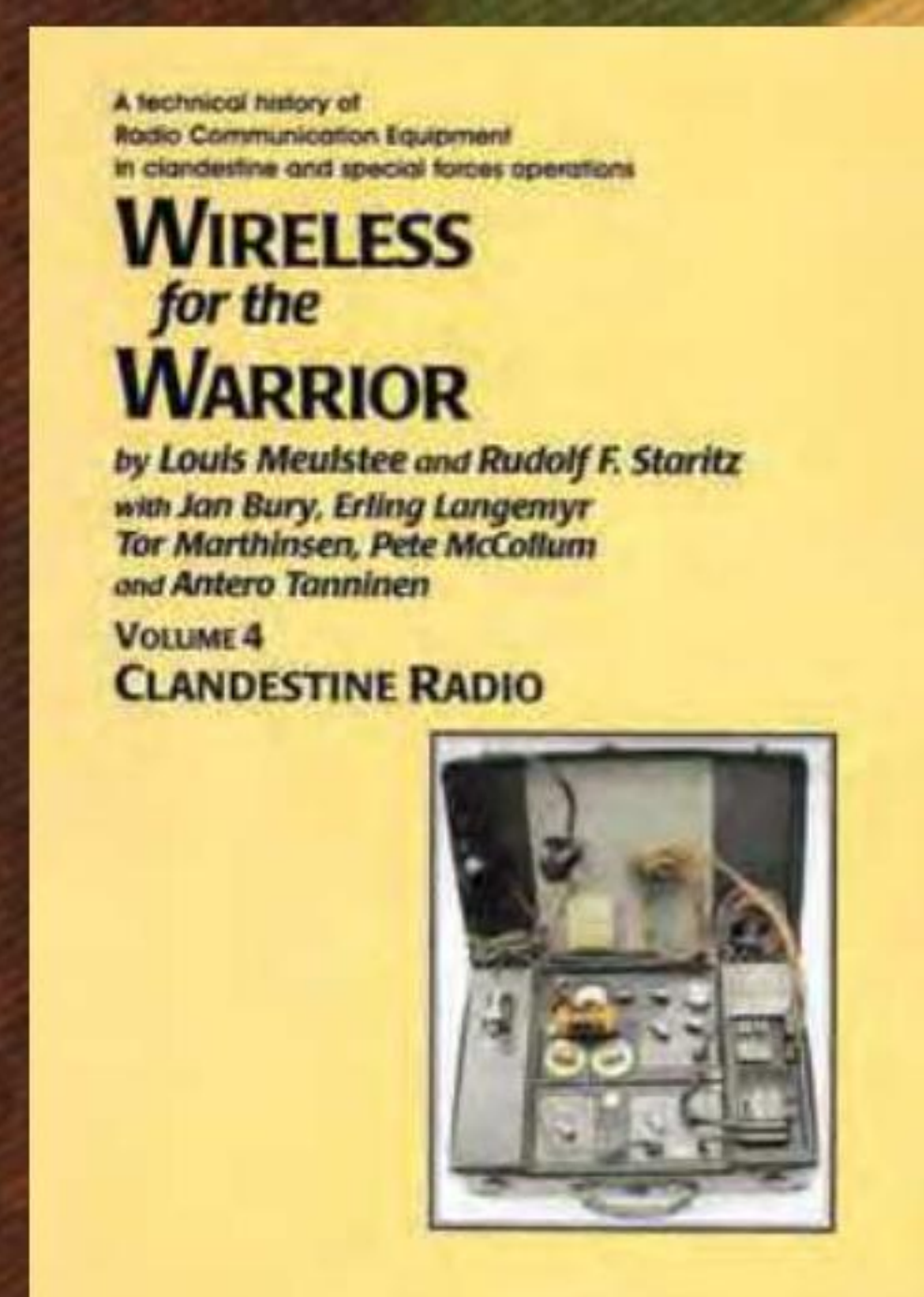
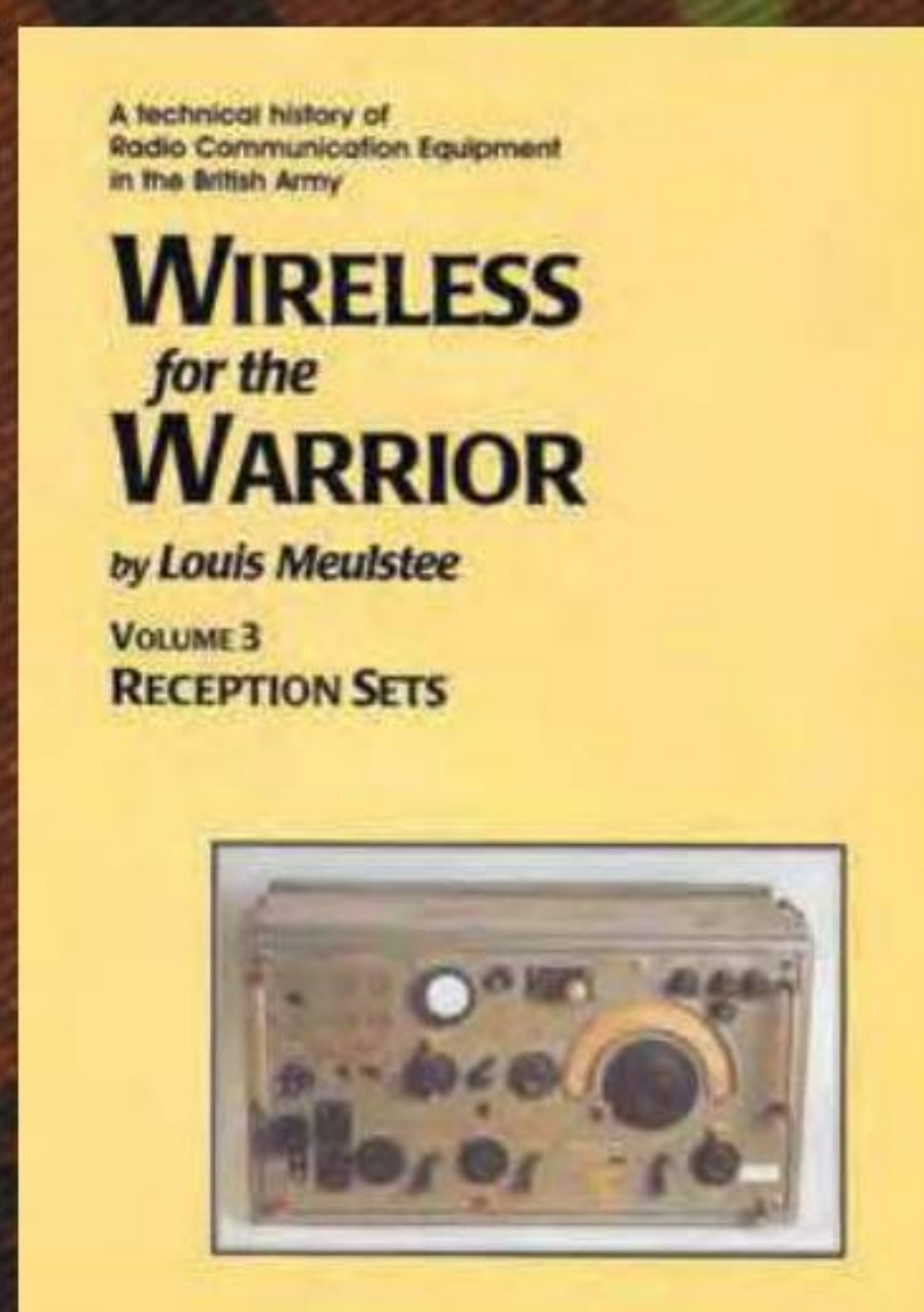
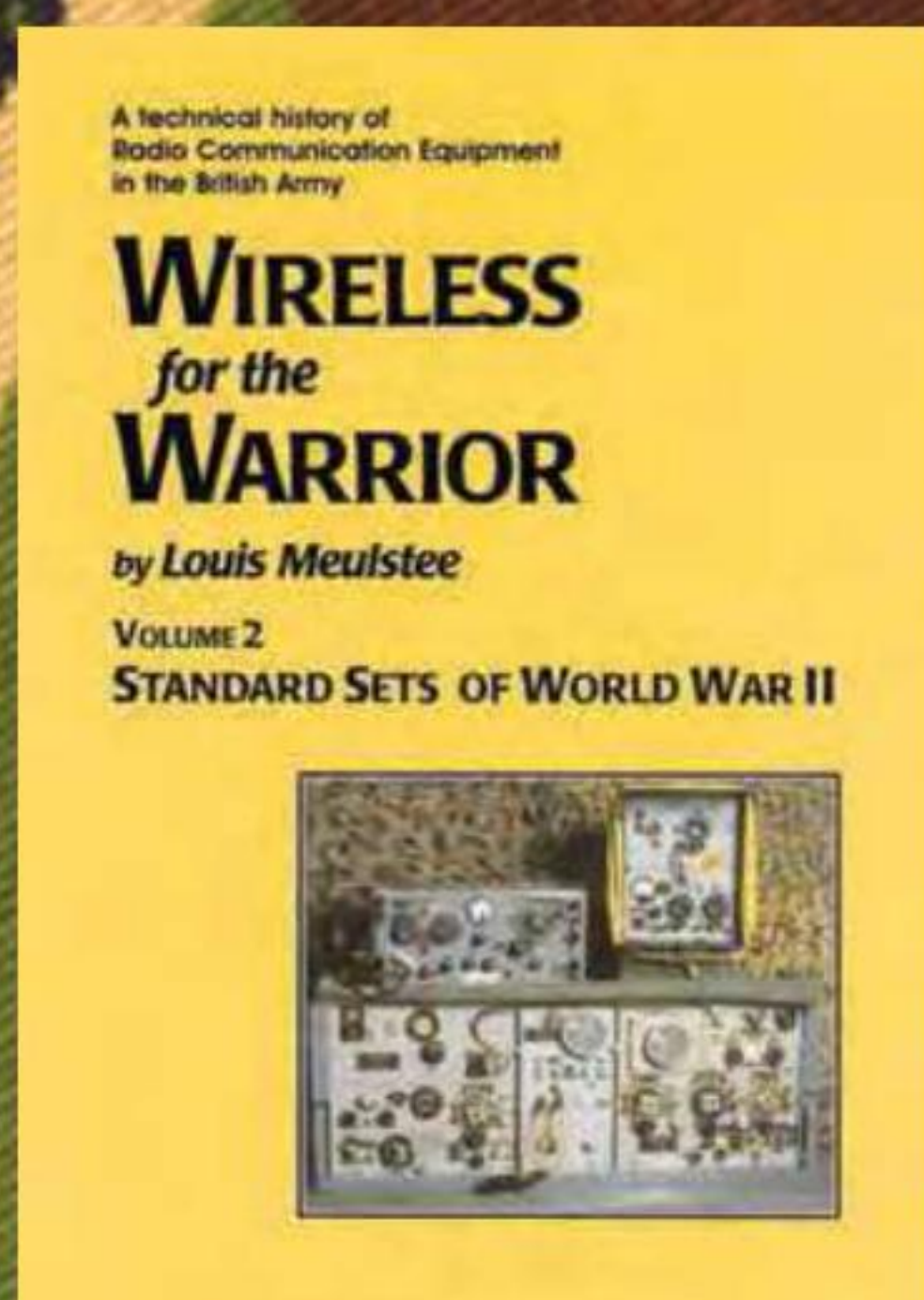
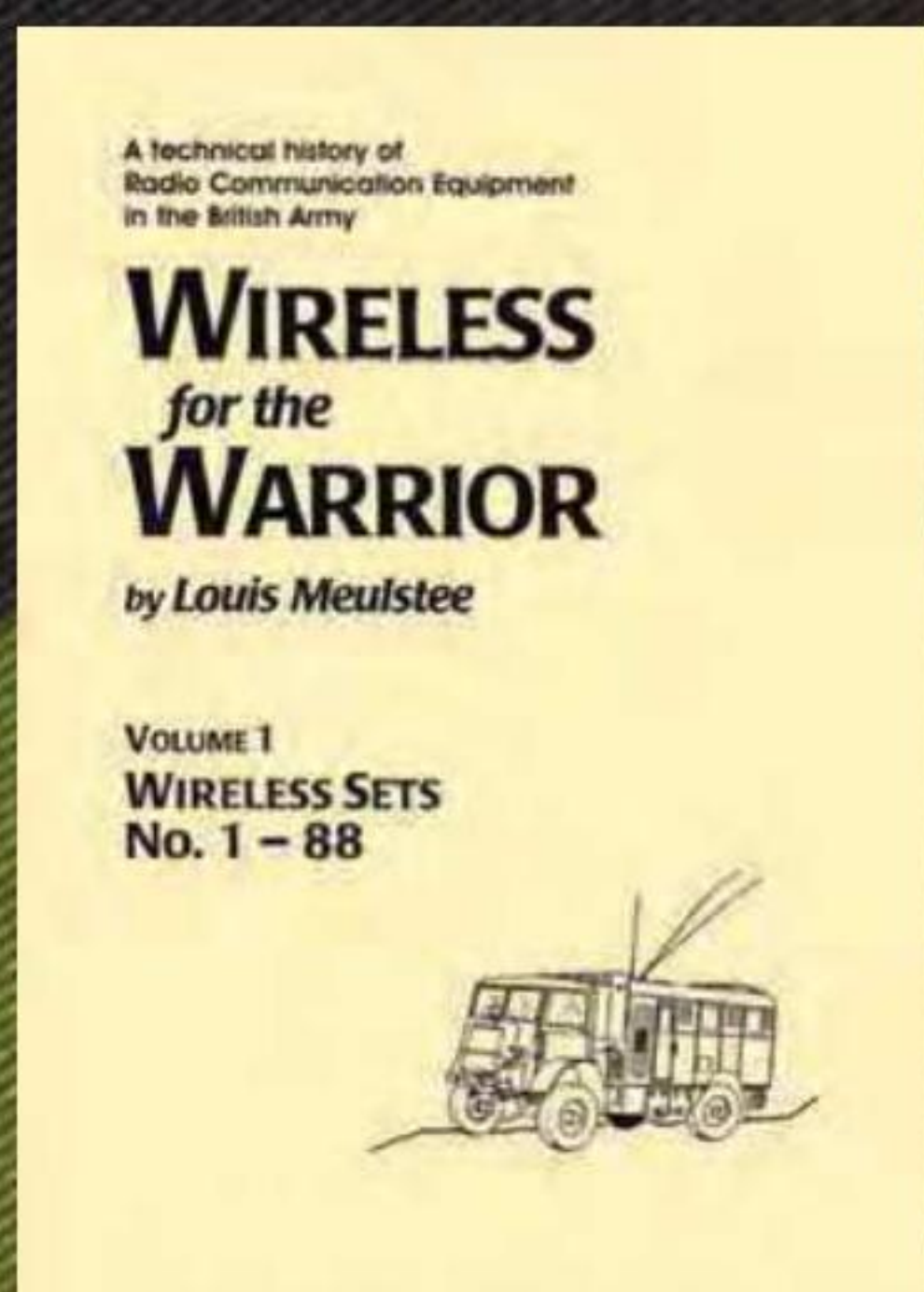
The books are very detailed and include circuit diagrams, technical specifications and alignment data, technical development history, complete station lists and vehicle fitting instructions.

Volume 1 and *Volume 2* cover transmitters and transceivers used between 1932-1948. An era that starts with positive steps taken to formulate and develop a new series of wireless sets that offered great improvements over obsolete World War I pattern equipment. The other end of this

timeframe saw the introduction of VHF FM and hermetically sealed equipment.

Volume 3 covers army receivers from 1932 to the late 1960s. The book not only describes receivers specifically designed for the British Army, but also the Royal Navy and RAF. Also covered: special receivers, direction finding receivers, Canadian and Australian Army receivers, commercial receivers adopted by the Army, and Army Welfare broadcast receivers.

Volume 4 covers clandestine, agent or 'spy' radio equipment, sets which were used by special forces, partisans, resistance, 'stay behind' organisations, Australian Coast Watchers and the diplomatic service. Plus, selected associated power sources, RDF and intercept receivers, bugs and radar beacons.



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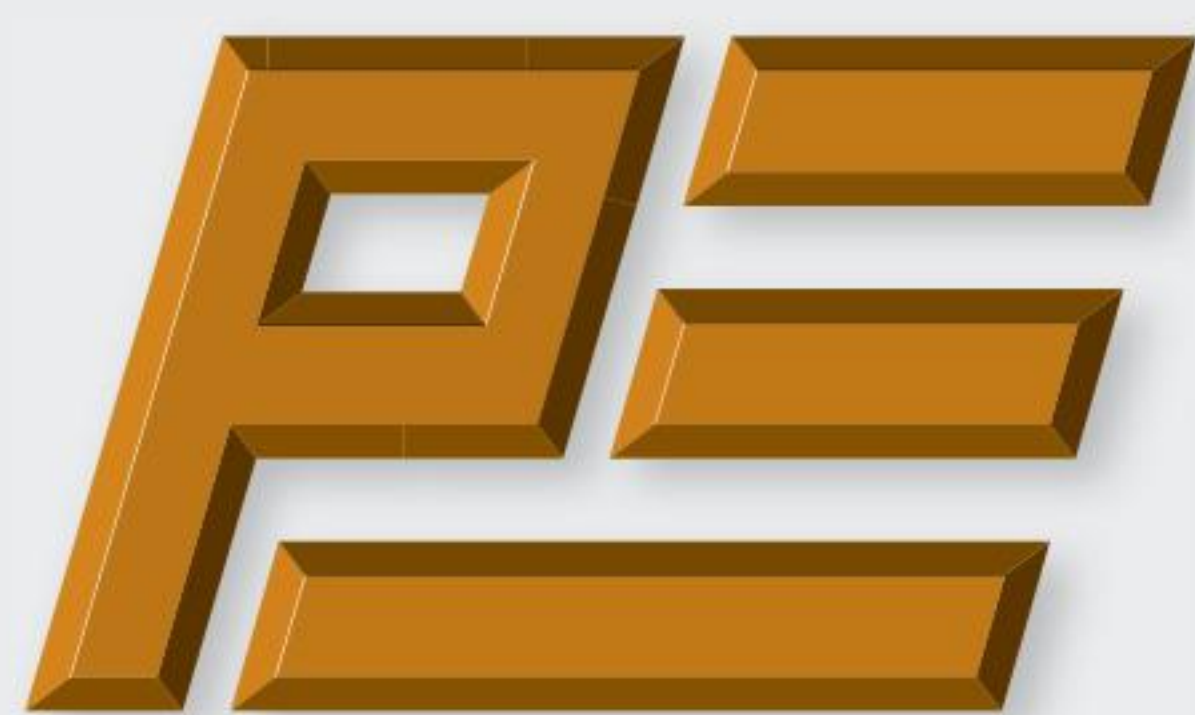


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Questions about articles or projects should be sent to the editor by email: pe@electronpublishing.com

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Ring, ring!

I've had a mobile phone for 25 years and the changes over that period in terms of cost, functionality and convenience have been phenomenal. My iPhone is always at hand, and when I carelessly lost it earlier in August I'm embarrassed to say it was quite a trauma! That said, I still have a landline, partly because it's part of the package that Virgin Media supply, partly because I get a better 'signal' and don't drop calls, and partly... well, simple nostalgia. I'm old enough to remember when a corded rotary dial phone was all there was, and I like having a phone on my desk. True, no Bakelite is involved in my current device – it's a nice Panasonic DECT cordless model – but it still feels like a landline... sort of. Anyway, the reason for this ramble is that for those of you who have an unused old phone lurking under your desk or in your workshop then we have the perfect project for you this month. The *Tele-com* lets you build a sophisticated intercom with 'proper' phones that ring the old-fashioned way. Good fun and well worth a read.

SMD tweezers

The other project I particularly enjoyed in the current issue shows you how to build a pair of clever, useful and inexpensive *SMD Test Tweezers* – simple but elegant DIY instrumentation for all you SMD fans.

Please!

Most of the communication we receive from readers is via email – pe@electronpublishing.com – and this is undoubtedly the best way to contact us. However, from time to time we also receive traditional paper letters, and these are of course welcome too. But, for those of you who prefer to use 'snail mail' I have one simple request. If you are making an order or expect a reply then please, please include at the very least your phone number and better still your or a friend's email address. All too often we find that hand-written orders can be hard to decipher or you forget an important item (eg, your postal address!) and we can't proceed with an order or even let you know that your order is never going to arrive. Just adding your phone number means we can easily contact you and sort out any issues. Thank you!

Matt Pulzer
Publisher

Forget leaves on the line!

Techno Talk

Mark Nelson

Why? Because Britain's railways may soon face a far greater threat to the running of their trains. It's something far more malign and hazardous – solar flares. And if the sun's ability to affect technology on Earth is as real (and imminent) as some experts think, essential infrastructure may be at risk. Time to panic? Let's investigate...

The origin of this concern is a presentation at a conference held in July by the Royal Astronomical Society at the University of Warwick. Cameron Patterson, a PhD student at Lancaster university, made the stark statement that fluctuations in space weather have the ability to disrupt railway signals and cause significant delays (and risk) to trains. Electric currents induced in signalling cables caused by solar activity can interfere with the normal operation of signals, even turning green signals to red when no other trains are operating nearby, he asserted.

Wild claim?

Outlandish as this may sound, his pronouncement was based on research by a team of researchers at the University of Lancaster, who have modelled the impacts of solar storms on two geographically separated stretches of the UK railway network. This followed investigations made in Sweden, where electrical field strengths of higher than 7V/km have been detected. Further investigation will now take place. Patterson stated: 'We are now working on looking at the case where trains are present on the line, and how strong a storm needs to be to turn a red signal back to green – a hazardous scenario potentially leading to crashes.'

Is this for real? Are railway signalling systems truly as vulnerable as this? Well, yes. What's more, according to a recent article in *Forbes* magazine, there is a genuine risk that a geomagnetic storm triggered by a burst of solar energy could also overwhelm our power grids, shutting down cell phone towers and crippling worldwide communications. A NASA webpage confirms that during solar storms, earth currents induced by the changing terrestrial magnetic field can be sufficient to induce voltages in long cables as well as in oil and natural gas pipelines.

In March 1989, during the peak of a sunspot cycle, the sun produced one of the most powerful storms ever

recorded. Surges in electrical power lines plunged large portions of Quebec into darkness and caused hundreds of million dollars of damage to power transformers. In the same year, a powerful pipeline explosion demolished part of the Trans-Siberian Railway, engulfing two passenger trains in flames when gas from a leak in the pipeline was ignited by the two passing trains.

How does this happen?

The solar cycle is around 11 years in length, and every 11 years or so the Sun's magnetic field flips completely. This means that the Sun's north and south poles switch places. It then takes about another 11 years for the Sun's north and south poles to flip back again. According to NASA, the current solar cycle is expected to peak in July 2025 and may well be weaker than average. This is fortunate, as effective precautions and the cost of replacing destroyed infrastructure would be horrendously expensive. The earth currents induced by high levels of solar activity develop only along lengthy metallic structures, so domestic electrical wiring and electronic devices are not affected. Another consideration is that solar flares impact territory only on the side of the Earth facing the sun.

Something more cheerful!

That's enough doom and gloom, so how about some comic relief? Following on from last month's selection of humorous or techie jargon words that some people use for electronic stuff, here are a few more funnies, thanks to my rediscovery of a long list I had misplaced.

Boatanchor (or **BA** or **anchor** for short): any radio, 'scope or other test gear made in a steel case (usually military types) may be considered a 'boatanchor'. Units produced from WWII until the mid-1960s are the most popular examples of the genre. Why 'boatanchor'? It soon becomes self-evident after carrying one of these to your car and you notice how much longer your arms have become.
Bottle: a valve or tube.

Bug, dead bug: integrated circuit.

Cheater cord: Some older TV sets had plug-in power cords that were captive to the back of the set, so when their owners removed the rear cover to look inside, they couldn't get shocked. The mains cord that repair shops used to bypass this safety feature and plug into the chassis was known as a 'cheater cord'.

Deck level: chassis potential of live Hi-Fi, radio or TV equipment.

Firebottle: another nickname for a valve or tube.

Fluid state: alternative term for hollow state (the opposite of solid state).

Freezing lotion: aerosol can of freezing liquid (ever so useful for identifying faulty capacitors, ICs and transistors that are overheating).

Griefkit: rhyming name applied to a revered brand of do-it-yourself radio and electronics construction kits, popular in Britain and the US from the 1950s to the 1980s. The name is stupidly misleading because the quality of these kits (and their superb manuals) has never been surpassed (although not every constructor could afford them or was up to the task of assembling them).

Muff: microfarad (μf).

Puff: picofarad (pf).

Rat Shack: US nickname for the much-loved but now defunct national chain of electronics hobby shops in the US; known in Britain as 'Tandy'.

Rattle can: aerosol squirt can.

Spaghetti: Systoflex (or similar) varnished fabric sleeving for protecting bare wires.

Suicide cord: a mains lead or power cord with a plug on one end and either bare wires or alligator clips on the other. It is or was used in radio and TV workshops to apply power to a chassis that had been taken out of the cabinet.

Three-wire fuse: contemptuous early term for transistor.

Tranny: transformer or transistor.

Tuning wand: a non-metallic (usually Delrin) tool made to fit and adjust a screw, slug or core of a tuned circuit component.

Widow-maker: See 'suicide cord' above.

Win a Microchip MPLAB Snap In-Circuit Debugger

Practical Electronics is offering its readers the chance to win a Microchip MPLAB Snap In-Circuit Debugger (PG164100) – and even if you don't win, receive a 15%-off voucher, plus free shipping for one of these products.

The MPLAB Snap In-Circuit Debugger/Programmer allows affordable, fast and easy debugging and programming of PIC, dsPIC, AVR and SAM flash MCUs and MPUs, using the powerful graphical user interface of MPLAB X Integrated Development Environment (IDE) version 5.05 or later.

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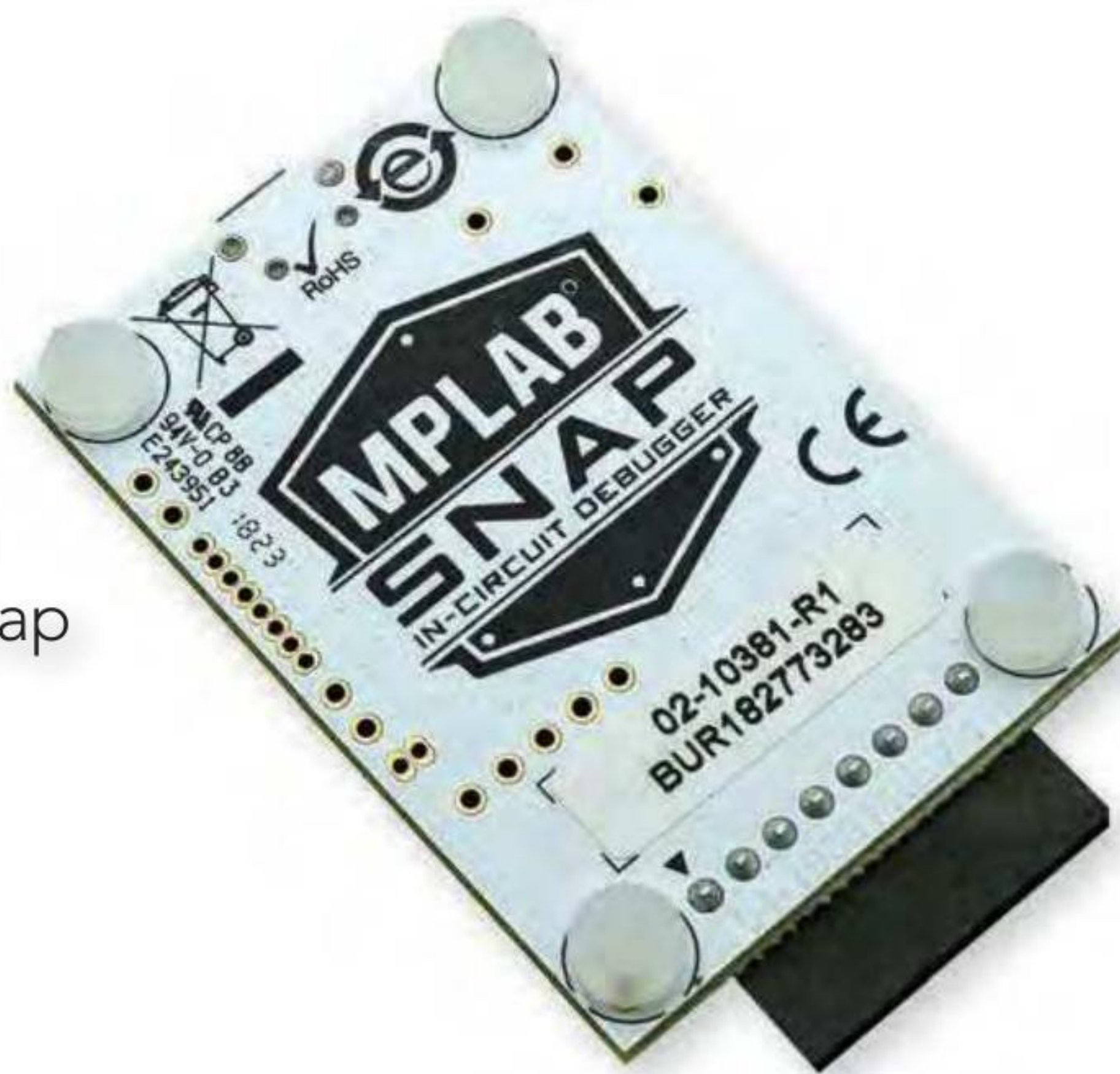
The MPLAB Snap can be connected to a computer using a high-speed USB 2.0 interface and can be connected to the target via an 8-pin SIL (single in-line) connector. The connector uses two device I/O pins and the reset line to implement in-circuit debugging and In-Circuit Serial Programming (ICSP). It has all the speed and features entry-level users need to quickly debug their prototype.

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The closing date for this offer is 30 September 2022

June 2022 winner

Marcin Jarosz

He won a Microchip SAM E54 Curiosity Ultra Development Board



The Fox Report

Barry Fox's technology column



A farcical system

Why do companies – like the telecom giants – make it look very easy to complain about their goods and services, even though the actual complaints process can be grotesquely difficult? Because they are under orders to do so.

Since 2015, UK businesses have been bound by the Complaints Handling Rules to offer customers the opportunity to complain. Companies must tell customers that if they are not satisfied with the outcome of a complaint, they can (after eight weeks of trying and within six months of failing) escalate matters to the Legal Ombudsman, which was set up in 2010.

Ofcom table

It all looks wonderful on paper. Early this year, Ofcom, the body tasked with controlling telecoms, published league tables for complaints received about the UK's major home phone, broadband, mobile and pay-TV firms.

The number of complaints, said Ofcom, had fallen to 'all-time low levels' with 'pay-monthly mobile complaints ... at the same historically low level as the last quarter.' Fergal Farragher, Ofcom's Consumer Protection Director proudly proclaimed: 'Complaints have fallen to a record low, and we expect providers to keep working to achieve the highest standards.' Perhaps it's because the

complaints process can be a waking nightmare of pass-the-buck confusion.

Working on the principle that a few documented facts are worth a lorry load of moans, I documented my experience of using Ofcom's complaints procedure. As with my documented experience of trying to complain to the ASA (Advertising Standards Authority) about smart meter adverts (see last month) the documents are available to anyone who has the clout to act on them. Again, if anyone wants to copy this article to their MP, feel free.

The essential basics

As previously reported in *PE*, I tried to complain on two counts about mobile provider Three. The company's website had continued to advertise its bargain-priced 321 Pay As You Go service (3p per minute speech, 2p per text and 1p per minute data) for at least three months after prices were hiked fivefold.

When I used my password-protected account with Three to query this, a series of staffers in Three's Customer Services, apparently based in India and with very poor ability to write understandable English, repeatedly and incoherently insisted on full disclosure of just the kind of security sensitive PII (Personally Identifiable Information) that the public is continually warned against revealing.

Three was demanding (sic): 'Password that you have Set on the Account as memorable place and memorable name. As you can verify your account with the password only, For security of your

account. So that we can help you get a better outcome on the account. Three will do its best to help you with a resolution. We would need below detail so that I can look into this query, please reply to us with your: Password (Memorable name or Memorable place)'

My reminders that I had only been able to contact Three's Customer Relations by using my Account password fell on deaf ears. So did my concern that employees were requiring open email reveal of Personally Identifiable Information (PII), such as Mother's Maiden Name. And so did my attempts at reminding them that once PII has been revealed it cannot be changed, unlike made-up passwords which can be endlessly changed.

This is of course why most companies and banks now ask only for partially revealed PII. For example, when I recently contacted telecoms company EE, the Help Line requested: 'For security, please can I take characters 1 and 4 from your customer services password on the account? Please do not supply your password in full.' That's the way to do it, Three. Take lessons from your competitors.

Executive decision

Using the recommended complaints system, I pursued the matter through to Three's Executive Office, providing date-stamped captures of Three's out-of-date web page and raising concern over Three's forced reveal of PII security data. Three's Executive Office claimed, 'We have access to archives, and I have checked our



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website (and) see no reference to 321. Is it possible this was on another site?’

Three’s Executive Office also supported its Customer Relations demands for PII personal data as ‘correct’ and ‘couldn’t have been avoided. We ask customers for two passwords and suggest these should be a memorable name and place. For now, this won’t change...there is (sic) no shortfalls in our process’.

And so, to the Ombudsman

So, I took the officially recommended next step and lodged a complaint with the Telecoms Ombudsman, filing copies of my correspondence with Three about PII security, along with captures of Three’s web site when it was displaying woefully out-of-date pricing.

The Ombudsman does not communicate directly by email; correspondence is posted on a secure noticeboard and alerts sent by email. While the system may be secure and easy to use for those who use it every day, it is far from intuitive. Complainants are asked to upload evidence in support of their case to this online board. Bizarrely, the list of file types that can be uploaded does not include HTML web page captures. So, the complainant must convert HTML files to another format such as pdf, which not only requires IT skill and specialist software but also will often alter the date of the capture, thereby undermining its value as evidence.

Fortunately, some of my captures were PNG files, which the Ombudsman’s system does accept. These show the capture date – but only if someone knows the simple method of revealing date metadata (Right Click, File Information or Properties, Details).

Three told the Ombudsman: ‘We have also checked our archive website and can see no record that the incorrect prices were advertised’.

The Ombudsman duly rejected my complaint. The Investigative Officer wrote: ‘You have provided screenshots which have been copied and pasted from Three’s website. These do not show the date these were grabbed.’

Could it really be true that the Ombudsman does not know how to check evidence file date metadata? The clue may be in the way the Ombudsman’s Investigative Officer then got himself in a monumental muddle over the timescale for filing an appeal against what looked like a technically flawed judgment.

Pass the buck

After failing to respond to queries the Investigative Office ‘extended the decision

window’ to a week earlier than the previously set deadline. I duly appealed the Ombudsman’s decision, explaining how to reveal the creation date of a graphics file (JPEG or PNG). The Ombudsman then reversed its decision, but on technicalities rather than the main issues, saying only equivocally ‘I find it more likely than not that it (Three) failed to update the information regarding its price change in a timely manner’ and adding ‘we are not able to impose any punitive fine or punishment as this action is outside of our remit and is the responsibility of Ofcom.’

The Ombudsman also backed Three’s right ‘to request a password in order to verify an individual’ – which was never in dispute – adding that the Ombudsman ‘cannot conclude whether an act or omission of a business constitutes a breach of the General Data Protection Regulations (GDPR). This is for the ICO (Information Commissioner’s Office).

Ofcom’s website also refers complainers to the ICO as well as the Telecoms Ombudsman.

In fact, I had already complained to the ICO as well as the Ombudsman. But – again side-tracking onto an issue that was never in dispute – the ICO brushed off PII data concerns by saying ‘we can confirm that the use of passwords for verification purposes is industry wide and is not a breach of the data protection framework. We suggest you contact the Ombudsman Service (as the most appropriate regulatory body) for further advice.’

So, the Ombudsman is referring complainants to Ofcom and the ICO, and Ofcom is referring them to the Ombudsman and the ICO, while the ICO is referring them to the Ombudsman. You couldn’t make it up. Actually, yes you could, if you were writing a *Yes Minister* script (https://en.wikipedia.org/wiki/Yes_Minister). I also filed a complaint with the ASA about Three’s out-of-date advertising. This triggered a request by the ASA for permission to identify me to Three as complainant, which I gladly gave. But then – in line with the ASA’s (previously described) new streamlined and customer-unfriendly procedure – I heard nothing further and was left to guess that someone, somewhere deep inside the ASA did not think the issue was worth pursuing.

Make a non-apology

The Ombudsman had reversed its decision on technicalities, so Three was told to apologise. I had asked for Three ‘to acknowledge mistakes, apologise and make a donation to an agreed apolitical charity.’ The apology which Three

offered contained no admission of any mistakes made and no commitment to make any changes, such as employing Customer Relations staff who are competent in the English language and stop requiring customers to compromise their data security by revealing PII secure data even after successfully entering their password.

I quote Three’s offered apology: ‘I’m sorry for the issues you had This will be used for feedback into the business to prevent further instances of this’.

You may think this inconsequential cotton wool does not add up to a meaningful ‘apology’. But the Ombudsman thinks otherwise and confirms it ‘meets the remedy requirements.’ For the sake of completeness, so that I would have fully documented evidence to show Ofcom, I used the Ombudsman’s own complaints system to complain about the Ombudsman’s handing of my complaint. Curiously, this process is conducted by conventional email, so is far easier to use. The Ombudsman’s Senior Customer Complaints Executive decently offered a ‘sincere apology’ and admitted that the Ombudsman ‘could have handled things better’. The Ombudsman also says it will now investigate its inability to accept HTML evidence. You may perhaps wonder why it needs a journalist to tell the Ombudsman’s IT people that if it is investigating complaints about websites, it should be able to accept HTML files as evidence. To tie things up, I asked Ofcom’s Fergal Farragher whether he has ever actually tried using his telecoms complaints system himself, and whether he would like to see my carefully documented experience of what happens when real-world people try to use it. Despite reminders, Ofcom’s Fergal Farragher never got back to me and no-one at Ofcom has asked to see the detailed evidence which shows what a Mad Hatter’s pantomime its complaints system is in practical reality.

But soon after my ignored offer, Ofcom’s designated Consumer Protection Director – still Fergal Farragher – issued another public assurance that, ‘the overall level of complaints has been consistently low over recent months’.

And Ofcom still misleadingly refers to ‘the number of complaints made to Ofcom’ when in the same breath Ofcom says crystal clearly that ‘Ofcom cannot resolve individual complaints, you should complain to your provider first (and) if you are unhappy...take the complaint to an independent ombudsman’. It’s another of those ‘you couldn’t make it up’ farces which UK officialdom does so well.

Net Work

Alan Winstanley

This month we check out a whole-home mesh wireless system that's at a bargain basement price. Was it too good to be true? We also look at the latest email clients for desktop users and there's exciting news about a forthcoming satellite launch; the first ever from British soil.

As regular readers know, since the days of dial-up Internet, *Net Work* has described various options allowing users to access the Internet at home. I still rely on hard-wired Ethernet cables for a few network connections, but Wi-Fi is increasingly used by most devices such as laptops and Chromebooks, printers, smart speakers, TV dongles, internet radios, security cameras, tablets, phones... the list is endless. I still use a number of Devolo adaptors to provide a network powerline connection (PLC) through the electrical ring mains, to areas where Wi-Fi or Ethernet can't reach. PLC adaptors can be handy for providing Internet access to devices that have Ethernet ports but no Wi-Fi, such as some smart TVs and personal video recorders. PLC networking is especially useful in older homes with thick walls or metallised insulation that block wireless signals (a problem also faced by smart meter installers), but PLC 'broadband-through-the-mains' requires 'clean' electrical circuits for best performance. Plug-in Wi-Fi extenders and repeaters are commonplace, but they're just another thing to set up,

tweak and worry about and they also take up a useful electrical socket.

Another fine mesh

In my case, Wi-Fi coverage is a bit patchy around the home, which can cause problems especially with my smartphone. The Wi-Fi connection to the router may drop altogether as I move around, and sometimes the phone falls back to 4G mobile data, or I have to manually switch the phone to another SSID (Service Set Identifier). As demand for reliable Wi-Fi increases, the trend is gradually moving towards always-on 'whole-home mesh' networking which provides totally seamless coverage as you move around the property, without worrying about changing wireless SSIDs.

The concept of mesh Wi-Fi originated in around 2015 by a tech start-up called Eero that piloted the idea in a handful of homes in the San Francisco Bay area. Eero then rushed to ramp up production to meet pre-orders from consumers eager to upgrade their Wi-Fi. Eero is now owned by Amazon, who recently also bought iRobot, the name behind Roomba vacuum cleaners. (Privacy experts are alarmed by the prospect of

Amazon getting to know the layout of your house and targeting expanded sales at homeowners as a result.)

More background on both Devolo and mesh networking was covered in *Net Work*, June 2019, when whole-home mesh Wi-Fi networking was in its relative infancy. Key IT brands of Wi-Fi mesh products include TP-Link, Tenda, Huawei, Netgear and Linksys, with products available through the usual retail channels. The UK's BT (British Telecom) sells a range of whole-home 'discs' that works with any broadband supplier, they say. An online survey can

help you choose the best BT solution, see: <https://shop.bt.com/brands/bt/whole-home-wi-fi>

The obvious solution to my Wi-Fi problems would be to upgrade my home network. Whole-home Wi-Fi systems offer 2.4/5GHz Wi-Fi and often have Ethernet ports (maybe only 10/100Mbps), which is important to some users. Depending on specifications, whole-home Wi-Fi can be relatively pricey to install from scratch, and typical prices for a starter kit might be £100-£250 or more. A 'Tri Band' system will cope better with more demanding use such as gaming or streaming video. When checking through the tech specs, note that terms such as 'AC1200' relate to the total traffic throughput of the router or hub, not the speed; 'AC' implies Wi-Fi 5 or 5GHz frequency (802.11ac), but Wi-Fi hubs will offer 2.4GHz as well. So, the '1200' signifies the total capacity or bandwidth (1200 Mbps) over both radio frequencies. Don't be fooled by any sales-speak: a higher number like 'AC5400' doesn't mean it's faster than AC1200, but it can handle a total of up to 5400 Mbps for more demanding applications. A typical AC1200 hub might carry 300Mbps on 2.4GHz and 867Mbps on 5GHz, for example.

Just AXing

The latest standard to be released is 802.11ax or Wi-Fi 6. Hence a new crop of 'AX' Whole-Home Wi-Fi products is coming onto the scene, but they're not cheap: one pair of AX5300 hubs can cost £250, and a higher-spec. Wi-Fi 6E (6GHz) system with built-in Zigbee and gigabit Ethernet is listed by Amazon at £799 for a three-pack. This would suit the most demanding (or affluent) Wi-Fi users looking to upgrade or future-proof their Wi-Fi network. They are backwards compatible with 2.4 and 5GHz, and Netgear publishes an excellent guide at: <https://bit.ly/pe-oct22-netg>

Whole-home wireless mesh routers are marketed as replacements for an existing Wi-Fi router, but upgrading an entire Wi-Fi system for whole-home mesh networking can throw up all sorts



Devolo PLC adaptors can provide Wi-Fi and Ethernet to locations where a router's Wi-Fi might not be able to reach.

of problems with some devices. Before migrating onto a new wireless mesh system it's well worth re-appraising an existing home network first.

Many network gadgets, including Amazon Fire TV sticks, Chromecast dongles, smart speakers and some security cameras are easy enough to switch to a new wireless network, assuming you still have all those logins somewhere. However, certain wireless IP cameras, for example, might need to be hooked to the router using an Ethernet cable to be set up again – a nuisance if the camera is installed halfway up a wall somewhere. In some cases there can be issues with Network Address Translation (NAT), port forwarding or Double NAT, complexities that go beyond the scope of this article, but Google offers plenty of resources. In short, a bit of hair-pulling and frustration can be expected with some network devices before everything is working smoothly again.

I soon realised that installing a new wireless mesh network from scratch wouldn't be trivial, so how about adding an inexpensive whole-home Wi-Fi network alongside my existing network instead? Although technically not very elegant, it could be a worthwhile stop-gap for the time being, and it might cure the pesky problem of Wi-Fi dropouts as I moved around the house.

At about the same time, I was tipped off about a whole-home wireless mesh brand that I was previously unaware of. A budget product line sold under the Mercusys brand promised a whole home mesh Wi-Fi system for just £20! The Mercusys Halo S12 is the cheapest in their line-up and the tech specs seemed sound enough: a set of two basic AC1200 units offering 2.4 and 5GHz bands in a single SSID would cover a typical home of up to 2800 square feet, they claimed. At such a low price, I thought it was worth a punt, so I bought four!

These duly arrived, complete with UK mains adapters and a single Ethernet cable to connect one of them to a router. As my main Billion 7800 router had no spare Ethernet ports, I hooked a spare 5-port TP-Link switch (needing yet another mains adaptor) to it and connected a Mercusys unit to that, to become the 'main' mesh router.

It turned out that Mercusys is a sub-brand owned by none other than TP-Link and, in keeping with its cut price, the Mercusys Halo S12 is as no-frills as you can get. The impenetrable plastic cubes are attractive enough but very lightweight and could almost be empty. Each unit carried two 10/100 Ethernet ports, but the only other feature seen is a push-button to 'Pair' it and a multicolour status LED. I added

some Bumpon stick-on feet underneath to stop the featherweight housings from flailing around.

A meshy setup

The included *Quick Installation Guide* is in 22 languages, but instructions consist of just a couple of paragraphs. I was very pleasantly surprised by the ease of setup: after hooking the 'main' unit to my switch and letting it settle down for a minute, I could log into a configuration web page using my tablet or phone (no need for an app here) where I created the SSID and password for the new whole-home mesh network without a problem. I also found that the Halo offers parental controls and a guest network. It was simple to add more Halo units using the Pair buttons (though a power reboot on each one helped the process along), giving me four units in total, dotted around the house. A number of smartphone apps are available that monitor available SSIDs, and I found the coverage was satisfactory, though one unit was reported as 'out of range' and had to be relocated a few yards closer. In fact, I found setup astonishingly easy and there was nothing not to like, especially for this kind of price.

Then came the job of moving some devices onto the new mesh network, which was a chore but largely uneventful. Interestingly, one of my three Amazon Fire TV Sticks connected to the mesh on the less crowded 5GHz frequency, but the other Fire sticks didn't. However, I decided to retain my Devolo PLC network to connect a wireless IP camera over the Devolo's Wi-Fi, as it records video nicely on the Synology NAS sitting on my router's LAN. I also retained my router's Wi-Fi for my wireless network printer located nearby.

One hurdle is my Samsung smart TV, which lacks Wi-Fi but has an Ethernet port. As the TV accesses video and music files hosted on the same Synology NAS, I've kept the TV on the same Devolo network as well, hooking an Ethernet cable to a Devolo Wi-Fi adaptor which also connects the IP camera wirelessly a few yards away. Migrating everything onto a mesh system is a future project, but I see little point in changing something that works satisfactorily already.

Another device on my network shopping list was a USB-to-Ethernet adaptor which would let me use my laptop at times when Wi-Fi was inaccessible. A



The Mercusys Halo S12 is an entry-grade whole-home wireless mesh system at a rock-bottom price. The author found it works surprisingly well. I connected it through a TP-Link switch to the router.

USB-C adaptor produced by TP-Link worked well enough when tested on a Devolo PLC Ethernet port, although network speeds were quite limited.

For just £40 for all four units, the Mercusys Halo S12 system is ridiculously cheap, but it's proving to be a low-cost way of adding Whole-home Wi-Fi to a domestic network for non-demanding applications. Both my smartphone and tablet now enjoy reliable connectivity using the new mesh network, and I have not noticed any problems with WhatsApp video calls or music streaming. It might be that this AC1200 product line is being 'run out' cheaply onto the consumer market to make way for faster products. Looking at some online reviews, it seems that not everyone managed to use this range successfully and they sought a refund. My own view is that if you're looking to update your home Wi-Fi, TP-Link's Mercusys Whole-Home solution is worth a try at these prices and represents a low-cost entry into wireless mesh networking. Shop around carefully, and search eBay and Amazon for any deals.

Time to revisit email

The obvious benefit of whole-home mesh Wi-Fi is that, wherever they are, devices like tablets or laptops can hop from one node to another without the user even knowing it. This always-on 'mesh' reminded me of a typical email setup and various ways of handling email traffic. Many Internet users have a Gmail account which is cloud-based so you can check the mail from anywhere with net access, whether on a desktop computer, laptop or smartphone. Users are given 15GB of free disk space to store mail, files and photos. (By visiting

<https://takeout.google.com> you can fetch all your data that Google holds in your various accounts – the results might surprise you.)

All that most users need to know is that their emails are ‘out there’ in the cloud somewhere, and Google takes care of all the hosting and archiving. No-one knows where the servers actually are. One alternative to Gmail is of course Microsoft’s Outlook, or there’s GMX Mail from Germany or the secure ProtonMail from Switzerland. ProtonMail used to claim that it was encrypted and they did not log user activity, but this claim unravelled in 2021 when it was shown that they’d handed over some sensitive user data to the French authorities.

Increasingly, IMAP is used for email, as the Internet Message Access Protocol acts like an ‘always on mesh’ of mail that you can access from any location. Many users, including the author, still prefer to use traditional POP3 email instead, though. This allows me to download mail, attachments and all, from the mail server onto a client machine where I can deal with it, archive it or delete it. If needed, mail can be ‘previewed’ by downloading the first kilobyte or two before deciding to fetch the rest. Messages can automatically be deleted from the server once they’ve been downloaded, or after so many days have elapsed.

Although POP3 isn’t designed as an ‘always-on everywhere’ system like IMAP, it’s easy enough to use it across multiple devices (laptops, smartphones and so on), simply configuring client software to leave mail on the server until you finally fetch it *in toto* using your main email client software. You can choose IMAP or POP3 in Gmail account settings: after logging in, go to Settings (gearwheel icon) then select Forwarding and POP/IMAP.

Thunderbirds are go

This brings me to the topic of email client programs currently available for desktop users. The popularity of cloud-based computing means that there’s less choice for mainstream Windows, Mac or Linux users but there is plenty of life yet in email software, especially if you prefer to manage email yourself rather than relying on a third party. Among the most popular email clients is Thunderbird, which is a free open-source program funded by donations and the Mozilla Foundation. After a long spell in the doldrums, this venerable email program recently had a major update and the latest version V.102 has a clean new look and better integration with your Mail, Address Book, Calendar, Tasks and Chat



Stunning first images from the James Webb Space Telescope show a star nursery called the Cosmic Cliffs in the Carina nebula, 7,600 light-years away. The ‘mountains’ are seven-light-years tall. (Image credit: NASA, ESA, CSA, and STScI)

windows. Thunderbird 102 is one of the best all-round email clients out there and it handles POP3 and IMAP mail. Interestingly, an Android version of Thunderbird is promised, which could be the ideal replacement for low-grade programs bundled with smartphones. Thunderbird V102 is freely available from: www.thunderbird.net

If you want a modern, private alternative to Thunderbird and your web browser then consider the Vivaldi browser, which is available for Windows, Mac, Linux and Android. Oslo-based Vivaldi places a strong emphasis on user privacy and anti-tracking, and the Vivaldi web browser now has a built-in email client called Vivaldi Mail 1.0 which manages multiple email accounts with ease. More details at: <https://youtu.be/bNU8cZbqDGU> or you can visit: <https://bit.ly/pe-oct22-viv>

Other worthy email clients include well-respected The Bat! by Ritlabs, which is described as a secure desktop client for Windows. It costs £45.95 for the Home version, and £57.95 for the Pro edition which also includes a portable version called Bat Voyager that can run from a USB stick. A trial is available from: <https://bit.ly/pe-oct22-bat>

Readers may be surprised to learn that the writer still uses arguably one of the best email client programs ever made – Eudora. Originally sold by Qualcomm, Eudora has many productive functions that are hard to beat, including a fast database search, templates and unmatched mail filtering features, useful as I have a massive email database covering business and personal use. It is miraculous that an old program born in 1988 and last released in 2006 operates at all under current versions of Windows, but operate it does, even if installation does need a little initial juggling. Many dyed-in-the-wool email users still swear by Eudora, and it was a major blow to learn that support for Eudora 7.1 was cast adrift when the program was finally shelved in 2006.

Today, the beloved email program has just a few glaring problems, including poor handling of HTML email and an inability to deal with UTF-8 character encoding used by many modern email programs. I’m used to seeing garbled punctuation like – ‘~good~’ – instead of curly quotes. The colourful history of Eudora is in an excellent article at: <https://bit.ly/pe-oct22-eud>

In 2018 Eudora’s source code (freely donated by Qualcomm) was picked up by a Canadian called Nick Werner-Matavka. For legal reasons Eudora was renamed, and ‘HERMES Mail’ was born as a Kickstarter project. The current version, which is basically Eudora 7.1, can be fetched from <https://bit.ly/pe-oct22-her> along with a patch for OpenSSL. Since then, a total rewrite of Eudora has been stuck in the mud as an unfulfilled crowdfunding project, its developer frustrated by Covid lockdowns, legal issues and cash flow... until now.

I’d given up on ever seeing a new release of Eudora, but the good news is that after a five-year gestation period, HERMES Mail 8.0, codenamed ‘Aurora’, is finally entering beta testing and has been slated for launch later this year. It’s possible that Aurora will be the final name, and it sounds like the Windows version is almost in the bag. A new indiegogo campaign for a risky Mac-compatible version is now under way (as Eudora was initially a Mac program), and readers will find up-to-date news at: <https://bit.ly/pe-oct22-her8>

I hope to get an early look at HERMES Mail 8.0 as I feel it’s a hugely significant alternative to Gmail, Outlook and Thunderbird. I’ll continue tracking developments, so watch this space!

Space news

Talking of space, in mid-July the first images from the new James Webb Space Telescope were released by NASA and they observed previously unseen stellar nurseries and obscured stars. The

‘mountains’ in the image show a star nursery in the Carina Nebula called the Cosmic Cliffs. A striking composite image was released of the Cartwheel Galaxy, which formed some 400 million years ago after a large ‘spiral’ galaxy collided with a smaller one. Many previously uncharted sights and breath-taking images await us as the Webb Space Telescope peers into the universe further than any human has ever done before. Many online resources are available at: <https://webbtelescope.org/resource-gallery>

Low-earth orbit (LEO) satellite operator OneWeb was bailed out two years ago by the UK Government and India’s Bharti Global, and the feeling at the time was that the Government had bought itself a satellite business but didn’t quite know what to do with it. There were early suggestions, quickly dismissed, that maybe the OneWeb network could be re-purposed as Britain’s satellite navigation network, after the UK was unceremoniously kicked out of the EU Galileo program following the Brexit vote; the EU pocketed Britain’s expertise and investment in Galileo though.

A revitalised OneWeb has had a good run since then, as previously described in *Net Work*, but in July OneWeb struck a deal with geostationary-earth orbit operator Eutelsat that will see the two merge to become a LEO/GEO super-operator. Eutelsat has precisely 36 GEO satellites against OneWeb’s 428. ‘The UK Government will retain the special share and its exclusive rights over OneWeb – securing the company’s future at the centre of the combined group’s global LEO business, national security controls over the network, and first-preference rights over domestic industrial opportunities’ said the UK Government. The deal is subject to final regulatory approval. Despite the Brexit fissure, both Britain and Europe have a history of working successfully together on major projects in the past, including Concorde, the Channel Tunnel, Airbus and military technology, and it’s hoped the merger will create ‘a single, powerful global player in connectivity’, says the UK Government.

Meanwhile, Elon Musk’s SpaceX continues to lob 54 Starlink satellites at a time into LEO. My computer colleague has installed several Starlink satellite systems for UK clients and he’s been amazed at the extremely slick setup and installation each time. Starlink in the UK costs £89 per month with £529 setup – see: www.starlink.com/map

Britain’s first space launch

Britain’s first active spaceport in Cornwall, south-west England, will see the



A LauncherOne space vehicle carried by Virgin Orbit’s 747 *Cosmic Girl* can take off from an ordinary runway and propel satellites into orbit. A maiden flight from Cornwall Spaceport is due this year.

maiden flight of Virgin Orbit’s UK launch later this year. The 747-based launch will carry six satellites including the ‘DOVER’ pathfinder satellite in an underslung rocket launcher. DOVER will transmit an ‘innovative new signal to provide data from space that can be used on the ground to obtain a position or an accurate time’, it’s claimed – the precursor to Britain building its own independent space-based navigation network using Positioning, Navigation and Timing (PNT) techniques instead of beaming GPS (or Galileo) data earthwards.

‘When it comes to getting off the ground, we contribute to the work of others rather than taking the lead ourselves’ wrote Britain’s Boris Johnson in the 2021 National Space Strategy, so a successful launch later this year would make the UK the first country in Europe to launch satellites into space from home soil, one of the Government’s key ambitions. The UK is fast positioning to become the key European satellite launcher.

The maiden flight from Cornwall will carry the first satellite constructed in Wales, and Boris Johnson also reminded us that ‘Neil Armstrong’s journey [to the moon] would never have happened without the engineering know-how of a chap from Anglesey [in Wales] named Tecwyn Roberts – we have for too long failed to properly embrace the opportunities that the space industry offers.’ You can read about the Welsh space flight engineer at: <https://bit.ly/pe-oct22-tec>

Other news

Following a spate of truck fires in Lincolnshire, England, involving refuse vehicles, householders are being warned of the dangers of discarding rechargeable batteries, or gadgets containing them, in their domestic waste. Several garbage trucks caught fire and suffered thousands

of pounds’ worth of damage when rechargeable batteries were crushed by the compactors, and battery fires also occurred back at the waste depot when batteries set fire to piles of waste. Lincoln is not alone, similar problems have been reported in Australia – for example, see the 7News report at: <https://youtu.be/nNBTE-XzzYU>

Amazon is increasing the price of its Amazon Prime subscriptions by 12.5% to £8.99 a month or 20% to £95 a year if paid annually, across Europe and the US. First launched in the US in 2005 at \$79 a year, the latest Prime increase is the first in eight years after it rose to \$99 in 2014.

At a time when YouTube is increasingly corrupted by adverts nagging visitors to sign up for ad-free YouTube Premium, it’s claimed that half of British consumers are unwilling to pay extra to avoid adverts on streaming services like these. When I checked, YouTube offered its ad-free Premium YouTube and Music package on a one-month trial for \$11.99/month, cancel any time, see: www.youtube.com/premium

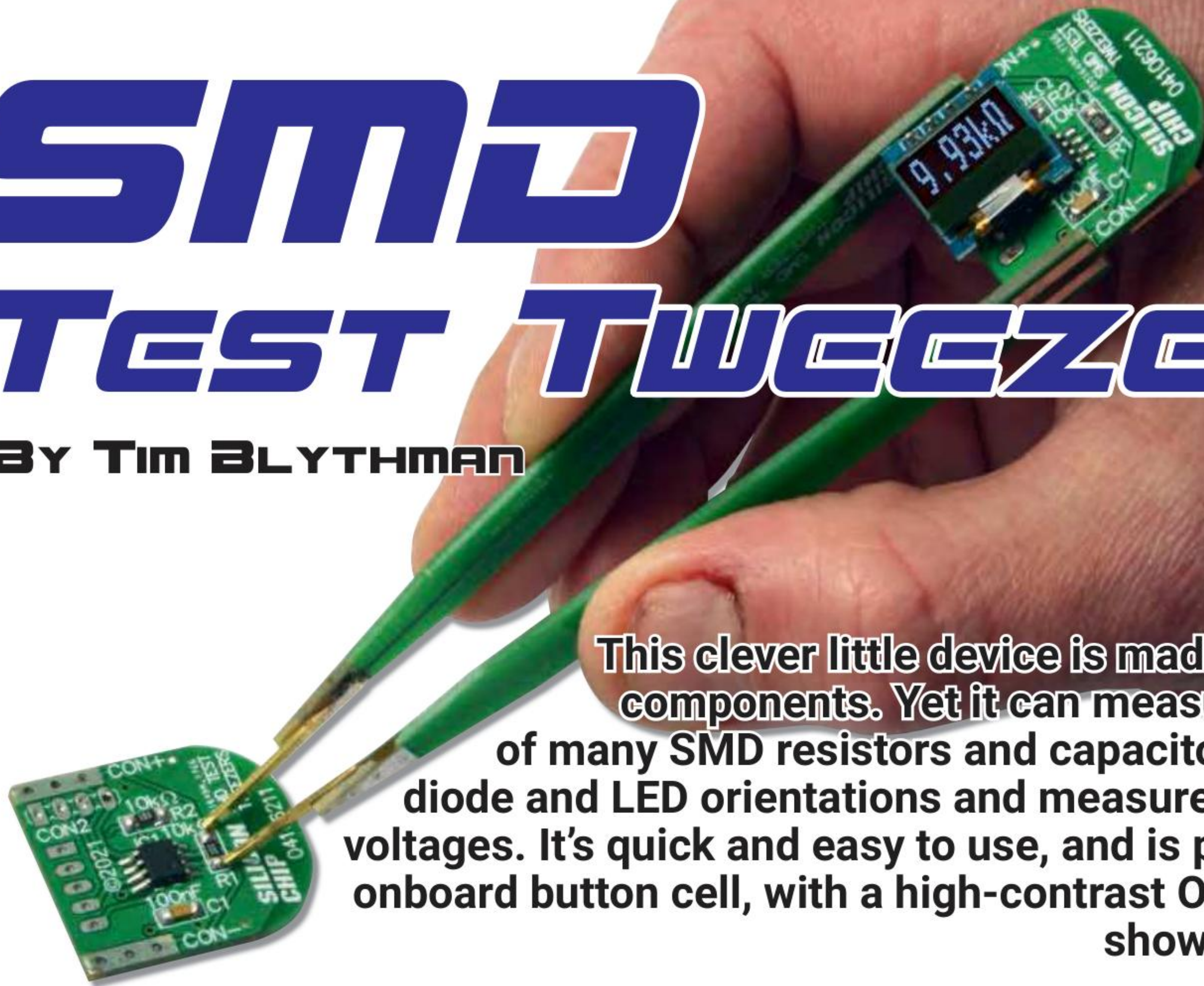
If you fancy a quick break from desktop drudgery, you might consider some of the casual games offered by Big Fish Games. They are graphically rich, clean fun for family use and not too demanding to play, so there is likely to be something for people of all age groups. Games typically cost \$9.99 and are downloaded for running directly on all major platforms. I found some old Big Fish titles from 2006 and installed them in Windows 10 and, remarkably, they worked perfectly 16 years later. Free trials are available from: www.bigfishgames.com

That’s all for this month’s column – see you next month for more *Net Work*.

The author can be reached at: alan@epemag.net

SMD TEST TWEEZERS

BY TIM BLYTHMAN



This clever little device is made from just 11 components. Yet it can measure the values of many SMD resistors and capacitors, plus show diode and LED orientations and measure their forward voltages. It's quick and easy to use, and is powered by an onboard button cell, with a high-contrast OLED screen to show the readings.

Working with SMD parts can be tricky. Reading component markings can be a strain on the eyes, if the component is even marked! Devices like SMD capacitors are totally anonymous and, once removed from their packaging, almost impossible to tell apart. These *SMD Test Tweezers* make it easier by telling you all about a component by simply picking it up.

In some cases, these *SMD Test Tweezers* can also measure the properties of a component once it has been soldered to a board (although, depending on the circuit configuration, sometimes the readings will not be accurate).

As time passes, fewer electronic parts are available in through-hole variants and increasingly manufacturers are building products mostly or entirely from SMDs. They are smaller and cheaper than through-hole parts, can be mounted on both sides of a board (often with internal traces

running underneath) and are also less sensitive to shock and vibration.

Of course, while parts being smaller can be advantageous, it also presents problems when working with them. Certain tools, such as tweezers and a magnifier, are indispensable.

Once you've had a chance to try out our *SMD Test Tweezers*, we think you will be adding them to your bag of SMD tricks!

The tweezers

SMD parts are very awkward to read with a multimeter. On many occasions, we've been pressing multimeter probes on to the ends of an SMD part, trying to get a reading, only for it to fly off and never be found again. Tweezers provide a much more natural way to do this, and as you don't need to apply much pressure, there is less chance of the part taking flight.

Even better, since tweezers are a convenient way to pick up and handle

such parts, if we incorporate the measuring tool into the tweezers, it can tell you what part you are handling while you are in the process of placing it on the board.

The *SMD Test Tweezers* measure whatever component is present between its tips, so there are no extra fiddly movements to make. You pick up the part, and the screen displays its assessment. The *Tweezers* automatically detect the difference between resistors, capacitors and diodes, including many LEDs. With a maximum applied current of 0.3mA at 3V, there's virtually no chance of causing damage.

The *Tweezers* can measure resistances from around 10Ω to 1MΩ, and capacitances from 1nF to 10μF. These ranges are slightly limited, but increasing them would significantly complicate the design, and a large percentage of SMD components fall within those ranges.

The *Tweezers* also check diode polarity and forward voltage. If an LED is picked up, it will also be illuminated dimly so that you can check the colour. The forward voltage measurement is limited by the 3V available from the small coin cell that powers it.

We've got no doubt that this tool will find much use in the hands of even our most SMD-savvy readers.

Design

We set out to make this tool compact, so it uses a tiny 0.49-inch (12.5mm) diagonal OLED screen. This is the same module we used in the *Shirt Pocket*

Features and Specifications

- Identifies and measures resistors, capacitors, diodes and LEDs
- Compact OLED display readout
- Runs from a single lithium coin cell, around five years of standby life
- Auto power on and off
- Displays own cell voltage when no component is connected
- Can measure components in-circuit under some circumstances
- Can perform thousands of measurements before the cell is exhausted
- Resistance measurements: 10Ω to 1MΩ
- Diode measurements: polarity and forward voltage, up to about 3V
- Capacitance measurements: 1nF to 10μF

Audio DDS Oscillator in the September 2021 issue.

We're also using a small 8-pin microcontroller, a PIC12F1572 in the SOIC package. It is a compact and capable part that puts some older 8-pin PICs to shame. And it's cheap too.

The design uses one small PCB to house the main operating parts, including the microcontroller, while another pair of PCBs form the arms. We added some custom brass tips to our prototype, but this is not absolutely necessary.

Another option is to purchase pre-made tweezer test leads that can be combined with the main PCB to give a similar result.

Circuit details

The complete circuit for the *Tweezers* is shown in Fig.1, and it is extraordinarily simple. The test functions are provided by a 10kΩ resistor connected between pins 2 and 5 of IC1. Pin 5 also connects to one of the *Tweezers* arms and thus to the device under test (DUT). The other *Tweezers* arm connects to IC1's pin 3.

All the tests are done by placing different voltages on pins 2 and 3, then using the micro's internal ADC (analogue-to-digital converter) to measure the voltage on pin 5 relative to the cell voltage. The cell voltage is also measured by using it as a reference to measure the micro's internal 1.024V reference.

CON2 is a 4-pin header that connects to the OLED module. This uses an I²C serial interface which is provided by pins 6 and 7 of IC1. The I²C pull-up resistors are fitted to the OLED module, so they are not needed in our circuit.

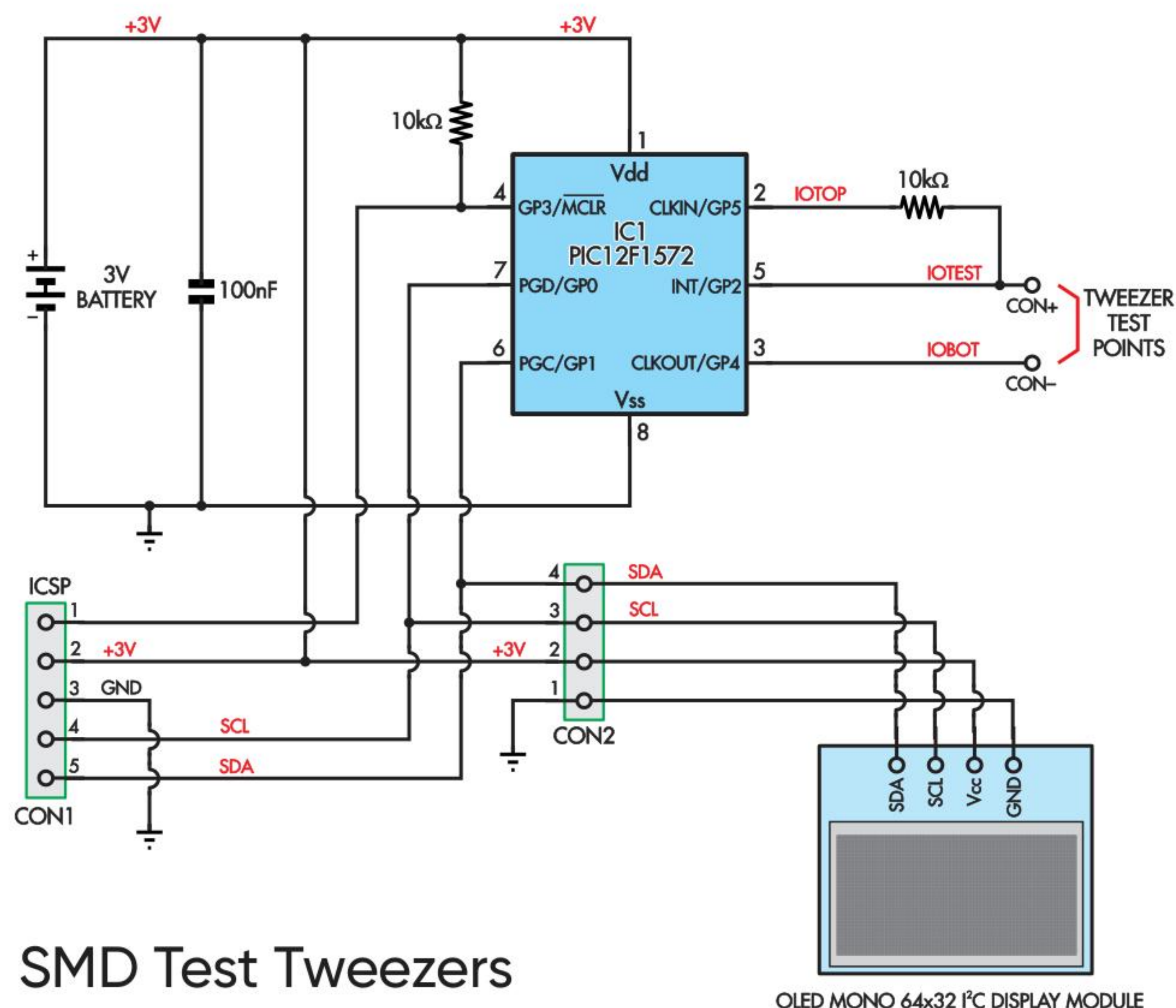
The PIC12F1572 does not have a hardware I²C peripheral, so these pins are driven 'manually' by the software. We've chosen pins 6 and 7 so that if IC1 needs to be programmed, it can be done before the OLED module is fitted, which would otherwise interfere with the programming signals.

Microcontroller IC1 is powered by coin cell BAT1, which is bypassed by a 100nF capacitor. IC1's MCLR pin is pulled up to its supply voltage by a 10kΩ resistor so that it operates normally as long as power is applied.

CON1 is an in-circuit serial programming (ICSP) header, with its pins connecting to IC1's pins 4, 1, 8, 7 and 6 respectively. You can use it to program IC1 in-circuit if needed. That is not necessary if you purchase a pre-programmed PIC chip.

Component sensing

The IOTOP and IOBOT designations on the schematic denote the normal



SMD Test Tweezers

Fig.1: the *Tweezers* circuit is remarkably simple; it uses just one resistor and three microcontroller pins to perform all its tests. An I²C OLED display keeps the pin count within the limits of the tiny 8-pin microcontroller.

Once the OLED screen is fitted, it will be tricky to access these parts, so check that everything is as it should be before proceeding further. With the four components fitted to the PCB, it should look something like this.



IO states of these pins. When idle, pin 2 is pulled high and pin 3 is pulled low. This matches the designations of CON+ and CON-.

On each measurement cycle, IC1 measures its internal 1.024V reference relative to its supply rails, and calculates the cell voltage based on this. This might be used later to calculate diode forward voltages; if no component is detected, the cell voltage is displayed.

The next test is to see if a capacitor is present. Pin 2 is taken low, and a series of samples are taken of the voltage at pin 5, until pin 5 is below half the cell voltage, or 255 samples have been taken.

If IC1 doesn't see the voltage fall like a capacitor discharging, it reports that it does not identify a capacitor. This can also happen if the capacitance is too low (which causes the voltage to drop faster than IC1 can make its measurements) or too high (which causes the voltage to not change enough over the sample period).

The capacitance is calculated based on the voltage drop and the time taken, although an approximation is used to avoid the computationally-expensive log function; our code comes within a handful of bytes of filling the available program space.

The accuracy of the approximation is only significant at values near the upper measurement limit. Given that many capacitors are only specified to within 20%, this is sufficient for most purposes and will be adequate to tell components apart unless they are very close in value.

The capacitance test is done first, as it means that the time since the last sample can be used to ensure that the capacitor is as close to fully charged as possible.

Note that you should not connect a charged capacitor to the *Tweezers* (or any similar meter). If it is charged to more than a few volts when it is connected, or the polarity is reversed, it could easily damage the microcontroller

IC1. Even if it doesn't, it will probably not be measured correctly.

If a capacitor is not detected, then the idle state is restored for 200µs (to allow the voltage to settle). The micro then takes a measurement of its pin 5 voltage, flips the polarity for another 200µs, takes another measurement and then flips the polarity back. The algorithm averages 16 samples at each polarity to improve accuracy.

Every second raw ADC measurement is adjusted to account for the fact that it was taken with reversed polarity. If the two voltage measurements are close, then the part is assumed to be a resistor and the value is reported according to the voltage divider formula (see Fig.2).

If one value is close to full rail and one value is not, then the part is probably a diode of some sort, and the forward voltage and direction are reported.

This can include LEDs, silicon and schottky diodes. The LED portion of phototransistors and opto-isolators should also show a diode reading. Bi-colour LEDs and other diode networks may not be detected, as they will conduct and not appear open-circuit in the reverse direction.

If you're smart, you can probably identify bipolar transistors by connecting the tweezers across their suspected base and emitter pins and identifying the junction polarity; it should be detected like a diode.

LEDs connected with their anodes to CON+ and cathodes to CON- will be forward-biased by the idle current and supplied with a few hundred microamps of current, which should be enough to light them dimly and indicate that they are working.

The Test current is quite low due to the 10kΩ resistor, no more than around 300µA. Thus, the forward voltage indicated may be a bit lower than what you might expect (eg, by reading the data sheet). For example, silicon diodes measure about 0.5-0.6V.

Once determined, the part type and value (or cell voltage) is displayed simply as a number with the appropriate units and multiplier; to differentiate the cell voltage from the diode voltage, a diode symbol is shown with polarity matching the part in relation to the Tweezer probes.

After five seconds of no part being detected, the OLED is put into a low-power mode, pin 5 is enabled as an interrupt source, and the

microcontroller goes into sleep mode. You can wake up the micro by simply touching the tweezer probes together, which changes the pin state.

So you can see how such a simple circuit can perform various tests to detect and measure a range of components. Fig.2 shows how these algorithms work in a bit more detail.

When the OLED is active, current consumption is around 4mA. This drops to 5µA when the microcontroller is sleeping, and the OLED is shut down. Thus, the cell life will depend mainly on the time the *Tweezers* are actually used. A typical CR2032 coin cell has a capacity of 220mAh, giving a standby life of around five years, which is good considering a coin cell has a typical 'shelf life' of 10 years.

Construction

If you haven't already jumped into working with SMD parts, you're going to start now because we've designed the *SMD Test Tweezers* with SMD components. Use the top and bottom PCB overlay diagrams shown in Fig.3 as a guide during construction. The main part of the SMD Tweezers is built on a PCB coded 04106211, which measures 28 x 26mm and is available from the *PE PCB Service*.

We recommend using solder flux (ideally paste, although a liquid flux pen is better than nothing), a fine-tipped adjustable iron, solder wicking braid and a magnifier. We also suggest using a pair of tweezers.

Since flux can generate smoke when heated, you should work somewhere with good ventilation. Also, check if your flux has a recommended cleaning solution; in a pinch, isopropyl alcohol is a good all-round substitute, with methylated spirits usually doing an acceptable job.

Start by securing the PCB to your work surface with the component side facing up. If you don't have a PCB vice or holder, use some Blu-Tack to stick it to your desk.

Apply flux to the pads for the SMD components, then hold IC1 in place. If all the leads are inside their pads, then that is fine. IC1 should have a small dot marking pin 1; ensure that this is at the end closest to the 100nF capacitor as marked on the PCB.

Clean the tip of your iron and apply a small amount of fresh solder. Then touch the iron to one corner pin of IC1. This should cause the solder to flow onto the lead. If the part looks to be flat against the PCB and still within all the pads, then solder the remaining leads by touching the iron to them.

You can add more solder to the iron if needed, and more flux can help too.

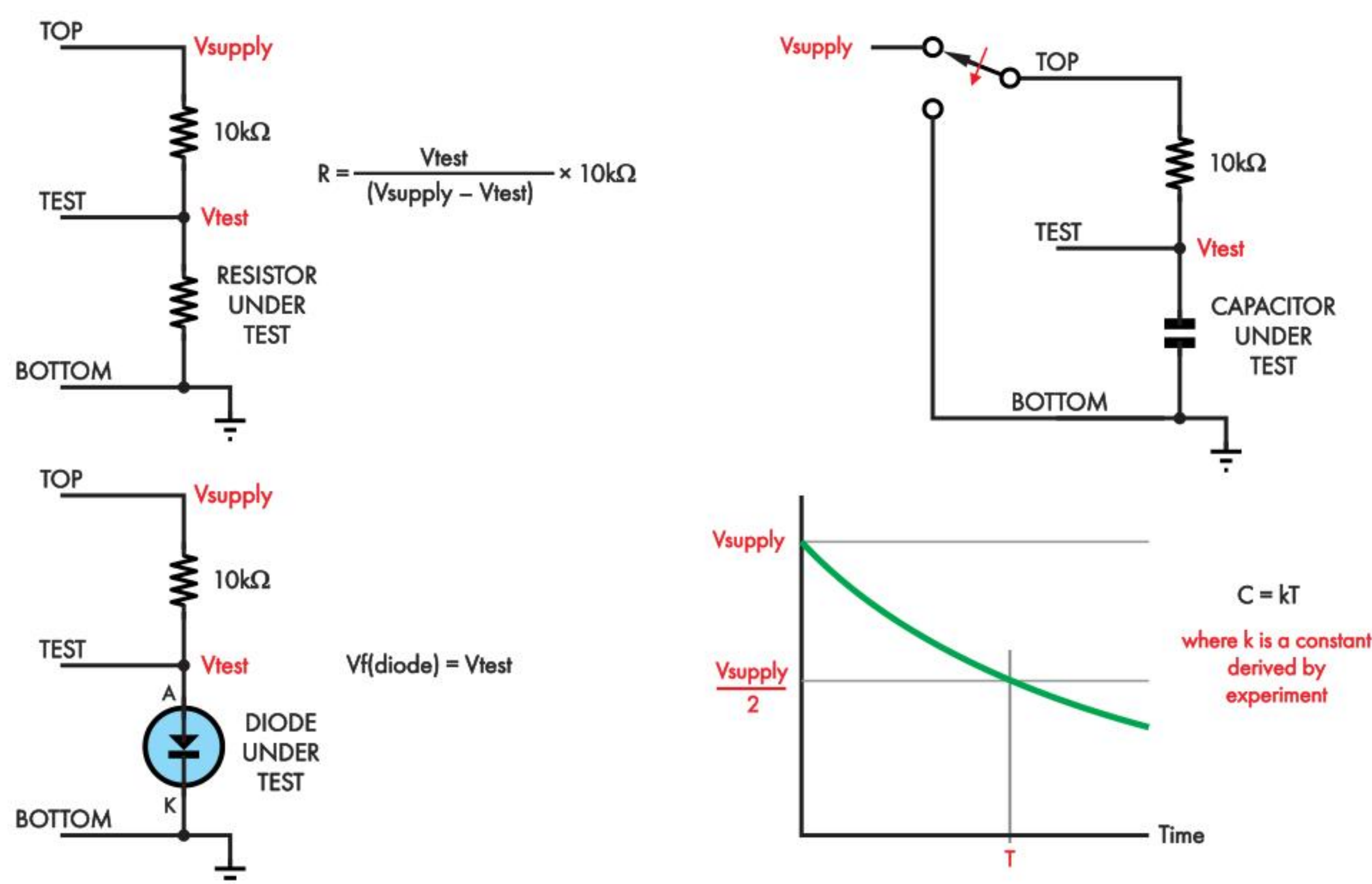


Fig.2: this shows the various ways that the Tweezers measure component values. Resistance is measured using the well-known resistance divider formula, while the diode test measures the voltage across the device in both directions. Capacitance measurement is based on the change in voltage over a time interval when discharged via the known resistance.



There's not much to see on the back of the Tweezers, but note that one arm, the OLED header (CON2) and the cell holder (BAT1) are all quite close together. Double-check for short circuits before fitting the coin cell.

The only problems with using too much flux are that it will generate more smoke and take a bit longer to clean up. Otherwise, more is generally better.

If you find that you have bridged any pins, then it's easiest to solder the remaining pins before fixing this, as it will help keep the IC in the correct place. Then apply more flux, press the braid against the bridged pins with your soldering iron, and gently slide the braid away once it draws up the excess solder.

Inspect the pins with a magnifier before proceeding, and repeat any of the above steps if necessary. You might need to clean up any residual flux if it impedes your view between the pins.

The remaining parts can be soldered similarly, with the difference being that none are polarised, and they all have much larger leads and pads.

Place the sole capacitor next; it will probably be the only part without markings. Solder one lead, check for correct positioning within the pads and against the PCB, then solder the other lead. Retouch the first lead if necessary.

Then fit the resistors; they are both the same value. They aren't polarised, but it's good practice to orient the markings to match the text on the PCB to help with troubleshooting.

Flip the PCB over to mount the cell holder. A similar soldering technique will work for the cell holder, with the difference being that it is a bit larger, so it will need more heat. Turn your iron up if it is adjustable.

Place the cell holder, ensuring that the opening faces towards the curved end of the PCB. If it looks like you might not be able to get the cell in or out, then it is probably the wrong way around. Apply some flux and tack one lead. Check that all is aligned correctly, then solder the other. You can then retouch the first pin if needed.



We've left our Tweezers bare to show the construction details, but you might like to cover the main PCB with a short piece of wide heatshrink. This will also serve to hold the coin cell in place.

That completes the surface-mounted parts, and this is a good point at which to clean off the residual flux. Because many flux cleaners are flammable solvents, you should allow the PCB to dry thoroughly after this step.

If you have a blank microcontroller, now is a good time to program it. Do it before installing the OLED module, as this can interfere with programming when plugged in.

Programming IC1

You'll need a PICkit 3 or PICkit 4 programmer to program this chip, plus the MPLAB X IPE (integrated programming environment) software, a free download from the Microchip website (usually bundled with the MPLAB X IDE).

You can also use a Snap programmer if you modify it according to the instructions on p.31 of our June 2022 issue (see the *PIC Programming Helper* project). This is necessary as the Snap programmer cannot supply power otherwise (or you could figure out another way to temporarily apply power to the micro during programming).

While it is possible to solder a programming header to the *Tweezers'* PCB, since it will only be used once

and would get in the way after that, we prefer to use gentle force to hold the header in place against the pads during programming.

Select the PIC12F1572 as the target part in the IPE, then open the **0410621A.HEX** file. After that, simply press the Program button to start the process (start to apply pressure to hold the header pins to the PCB just before you do that).

If you get the 'Programming/Verify complete' message, then programming has completed successfully. Otherwise, try again.

Detach the programmer before moving on to the next step.

Completion

If you want to add metal tips to the arms of your *Tweezers* (PCBs coded 04106212, measuring 100 x 8mm and available from the *PE PCB Service*), it is easier to do so before fitting them. Cut brass strip roughly to size – only trim to matching lengths once the *Tweezers* have been assembled.

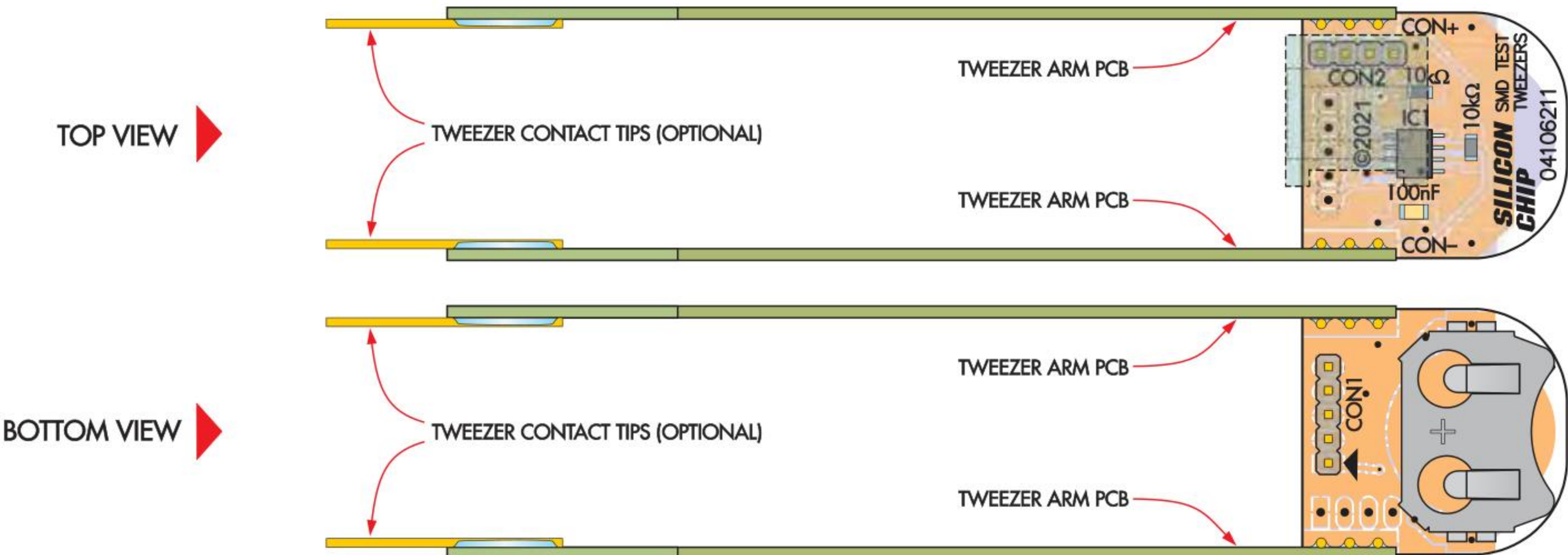


Fig.3: despite only a handful of components being present, we have used both sides of the PCB. One advantage of SMD components over through-hole parts is that it's much easier to have parts on both sides without concern over where the leads go. Keep an eye on IC1's orientation; once it's fitted, the rest of the assembly is quite straightforward.

Fig.4: there are no components mounted on the arm PCBs; they are basically just flexible conductors that are soldered to the main PCB and clamp the DUT at the other ends.

Solder one strip to the end of each arm, letting each overhang by around 5-10mm. Keep in mind that the bars should be on the inside of the arms when assembly is complete (see our photos for details).

The surface-mounting copper pads are essentially glued to the PCB, so it doesn't take much to tear them off. So, try to get some solder into the holes in the PCB, as this will add mechanical strength.

If you don't have brass strip, it will pay to add some small blobs of solder to the *Tweezers'* tips. This will provide a larger contact area and also some resistance against the tips wearing down.

Place the arms onto the *Tweezers* PCB at the CON+ and CON- pads and roughly align their positions. Their ends should be separated about 10-15mm with no pressure applied; this gives a reasonable working force and range. This gap also means that the *Tweezers* can be used to test through-hole parts like axial-leaded resistors, diodes and capacitors.

We found that fitting the arms flush with the edge of the PCB made the soldering easier and kept the CON+ arm clear of the CON2 OLED connection. It also looks tidier; see our photos.

Once you're happy with their positions, apply a generous amount of solder to both sides of the joins to secure them in place. Try out the action, tension and alignment of the arms and adjust if necessary.

You can also trim and dress the tips if fitted. Squeezing the arms together and drawing a fine file over the tips will align them if they are slightly different lengths.

To make the tips of the arms parallel, place fine sandpaper or a flat file between the tips and work them until the tips are satisfactory. This will also help add some texture to the tips to help them grip components and avoid the possibility of them flying off into the yonder!

The OLED screen

The OLED module is the last piece to fit. The header supplied with the module has a spacer of just about the right depth to mount the OLED parallel to the main PCB, although the pins probably need trimming.

Start by soldering the pin header to the PCB at CON2, preferably with the longer pins facing up. This will make them easier to trim later. Check that there are no bridges between the pins of CON2, the CON- arm and the cell holder.

Tack one lead of the OLED to the top of the header and check that it looks right and is not touching anything underneath; adjust it if necessary. Solder the remaining pins and then trim the excess pin length from the top, taking care not to damage the OLED screen. Then remove the protective film on the display.

Using it

Insert the lithium cell with the negative terminal against the PCB. The OLED should spring to life and show a reading just over 3V for a fresh cell. Squeezing the arms together should show a resistance of a few ohms.

If you have no display at all, check the OLED connections. If there is no resistance measurement, you might

have a problem with your test circuitry; check the resistors, IC1 and the *Tweezer* arms.

After the *Tweezers* go into sleep mode, they use low-power digital sensing to wake up. Thus, they might wake up if connected to some but not all parts. Reverse-connected diodes and high-value resistors may not wake the *Tweezers*, but nearly all capacitors (when discharged) appear to do so.

In that case, simply short the *Tweezer* tips together, then probe the component. Once a part has been detected, the *Tweezers* will stay awake until no part has been detected for five seconds.

Caution

Like any project that uses coin cells, the *Tweezers* should be kept well away from children who may ingest them. The *Tweezers* also have quite pointy tips, another reason to keep them out of reach of curious young fingers.

You can apply a piece of wide, clear heatshrink tubing to the main PCB body to insulate and protect it. This can also be used to secure the coin cell in place; it should not be due for replacement too often, and the heatshrink can be cut and replaced at such times.

You might also like to fit some thinner heatshrink to the arms. This will provide more insulation and also add a softer gripping surface to the *Tweezers*.



You can get pre-made tweezers with leads designed to be connected to other pieces of equipment like a multimeter. If you prefer these, you can cut off the banana plugs and solder them to our main board instead of our PCB-based arms. If doing this, ensure that the positive lead goes to the CON+ pad on the PCB and CON- to the black lead.

Parts List – SMD Test Tweezers

- 1 double-sided PCB coded 04106211, 28 x 26mm (main PCB) available from the PE PCB Service
- 2 double-sided PCBs coded 04106212, 100 x 8mm (Tweezer arms) available from the PE PCB Service
- 1 PIC12F1572-I/SN or PIC12F1572-E/SN 8-bit microcontroller programmed with 0410621A.HEX, SOIC-8 (IC1) – **available from the PE PCB Service**
- 1 0.49-inch 64x32 I²C OLED module [eBay, AliExpress – for example, at the time of writing eBay item 273942316375]
- 1 surface-mount coin cell holder (BAT1)
[Digi-key [BAT-HLD-001-ND](#), Mouser [712-BAT-HLD-001](#) or similar]
- 1 CR2032 or CR2025 lithium button cell
- 1 5-pin right-angle male pin header (CON1; **optional**, needed for programming IC1 only)
- 1 100nF SMD 50V X7R ceramic capacitor, 3216/M1206 size [Altronics [R9935](#)]
- 2 10kΩ 1% SMD resistor, 3216/M1206 size [Altronics [R8188](#)]
- 2 15 x 2mm short pieces of thin (eg, 1mm) brass sheet for Tweezer tips (**optional**)
- 1 40mm length of 30mm diameter clear heatshrink tubing (**optional**; see text)
- 2 100mm lengths of 10mm diameter heatshrink tubing (**optional**; see text)

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Teach-In 9 – Get Testing!

This series of articles provides a broad-based introduction to choosing and using a wide range of test gear, how to get the best out of each item and the pitfalls to avoid. It provides hints and tips on using, and – just as importantly – interpreting the results that you get. The series deals with familiar test gear as well as equipment designed for more specialised applications.

The articles have been designed to have the broadest possible appeal and are applicable to all branches of electronics. The series crosses the boundaries of analogue and digital electronics with applications that span the full range of electronics – from a single-stage transistor amplifier to the most sophisticated microcontroller system. There really is something for everyone!

Each part includes a simple but useful practical test gear project that will build into a handy gadget that will either extend the features, ranges and usability of an existing item of test equipment or that will serve as a stand-alone instrument. We've kept the cost of these projects as low as possible, and most of them can be built for less than £10 (including components, enclosure and circuit board).

FREE COVER-MOUNTED CD-ROM

On the free cover-mounted CD-ROM you will find the software for the PIC n' Mix series of articles. Plus the full Teach-In 2 book – *Using PIC Microcontrollers – A practical introduction* – in PDF format. Also included are Microchip's MPLAB ICD 4 In-Circuit Debugger User's Guide; MPLAB PICKit 4 In-Circuit Debugger Quick Start Guide; and MPLAB PICKit4 Debugger User's Guide.



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Tele-com

Intercom using analogue phones



Put your old analogue telephones to use and build an intercom! Perhaps you have a classic telephone like our red 'batphone', or one of the other Bakelite phones with a real bell that generates a fantastic ring sound. Now you can not only hear it again but actually speak to someone at the other end!

Technically, the **Tele-com** is a 'private line automatic ringdown unit', known in the industry as a PLAR. That means that it allows two PSTN telephones to be automatically connected by simply lifting one handset. Colloquially, though, most people would just call it an intercom.

Because of this, the device which allows the *Tele-com* to operate is referred to as the OzPLAR.

If you need two-way communication between two nearby locations such as a house and a shed, or a granny flat, or just two rooms in a home, it doesn't get much more convenient than this. Pick up the phone and the other end rings, then when the other person picks up, you can have a conversation.

While much of the telephone network still supports analogue telephones, we suspect that many people (like us) simply haven't bothered plugging them in, and now have a box of spare phones. Rather than throw them away, now you can put them to good use.

The central OzPLAR unit to which both telephones are connected (described in this article) performs the following functions;

- Provides power to the phones ('transmission battery feed').
- Detects when a phone is picked up ('off-hook detection').
- Automatic ringing of an electromagnetic or electronic AC bell.
- Ringing uses standard PSTN cadence – Australia/NZ/UK/EU/USA (long and short) selectable.
- The caller hears a ringtone while the called telephone is ringing.
- Upon answer, ringing ceases and a speech path is established between the two telephones.
- Both telephones must be replaced on-hook after a call before a new connection can be established.
- Ring-trip (stopping the ring signal) occurs during either the silent or ringing period, when the called telephone is taken off-hook.

The design is based entirely on discrete components and logic ICs, and has been designed with flexibility in mind. The PCB accommodates various alternative parts for the battery feed and the ringing generator. See the features panel for more information.

Circuit details

The complete circuit of the *Tele-com* is shown in Fig.1 and Fig.2, with

Fig.2 having the ring-related circuitry (including cadence generation), and Fig.1 the rest. The overall circuit has a few basic jobs:

1. Power the telephones
2. Detect when one is picked up
3. When a call is initiated, cause the called phone to ring and send a ringtone to the calling phone
4. When the other phone is picked up, stop the ringtone and establish voice communications
5. Reset the system when both phones are restored on-hook

To achieve this, it consists of multiple interconnected circuit blocks. The left-hand section in Fig.1 is the battery feed and loop detect/ring trip circuit, while the middle section is the logic engine which detects line status (off-hook/on-hook) and ensures that ringing output occurs only when the first telephone goes off-hook.

The far-right section in Fig.1 includes the components required to add an optional polarity reversal on answer ('ROA') to the calling telephone. Public telephones (PT) connected to Step-by-Step and ARF crossbar switching systems in the now discontinued PSTN used the reversal of the line polarity as the signal to deposit

Features of the Tele-com

Can be run from 2 x 12V batteries for an off-grid, portable or temporary setup

Powered from a 24V DC inline power supply; no mains wiring is involved

Ring tone is provided to the calling party

Support for 48V DC power input (optional)

Superior audio performance over longer/mismatched lines (using an IC-based battery feed)

20Hz ringing supply for improved ringing of mechanical bells

Support for optional bespoke cadence

Choice of inductor-based or solid-state battery feed

Onboard jumpers (or an external switch) to select AU/NZ/UK, EU or two variations of the USA cadence

Crystal-locked source for the cadence generator and ringing inverter requires no adjustments

Easy to build using readily available parts

the caller's money in the coin tin. This option requires 48V operation to work.

Off-hook detection and ring trip

When a telephone is taken off-hook, current passes through the optocoupler LED associated with the calling telephone (OPTO1 for the one plugged into CON3/4 or OPTO2 for CON5/6). Its output transistor therefore conducts and initiates a series of events to ring the other telephone.

The voltage across each optocoupler LED is limited by zener diodes ZD1 and ZD2. At the same time, a low-pass filter ($470\Omega/220\mu\text{F}$) bypasses 20Hz ringing signals around the optocoupler LED in the called telephone circuit, to prevent it from conducting during ringing.

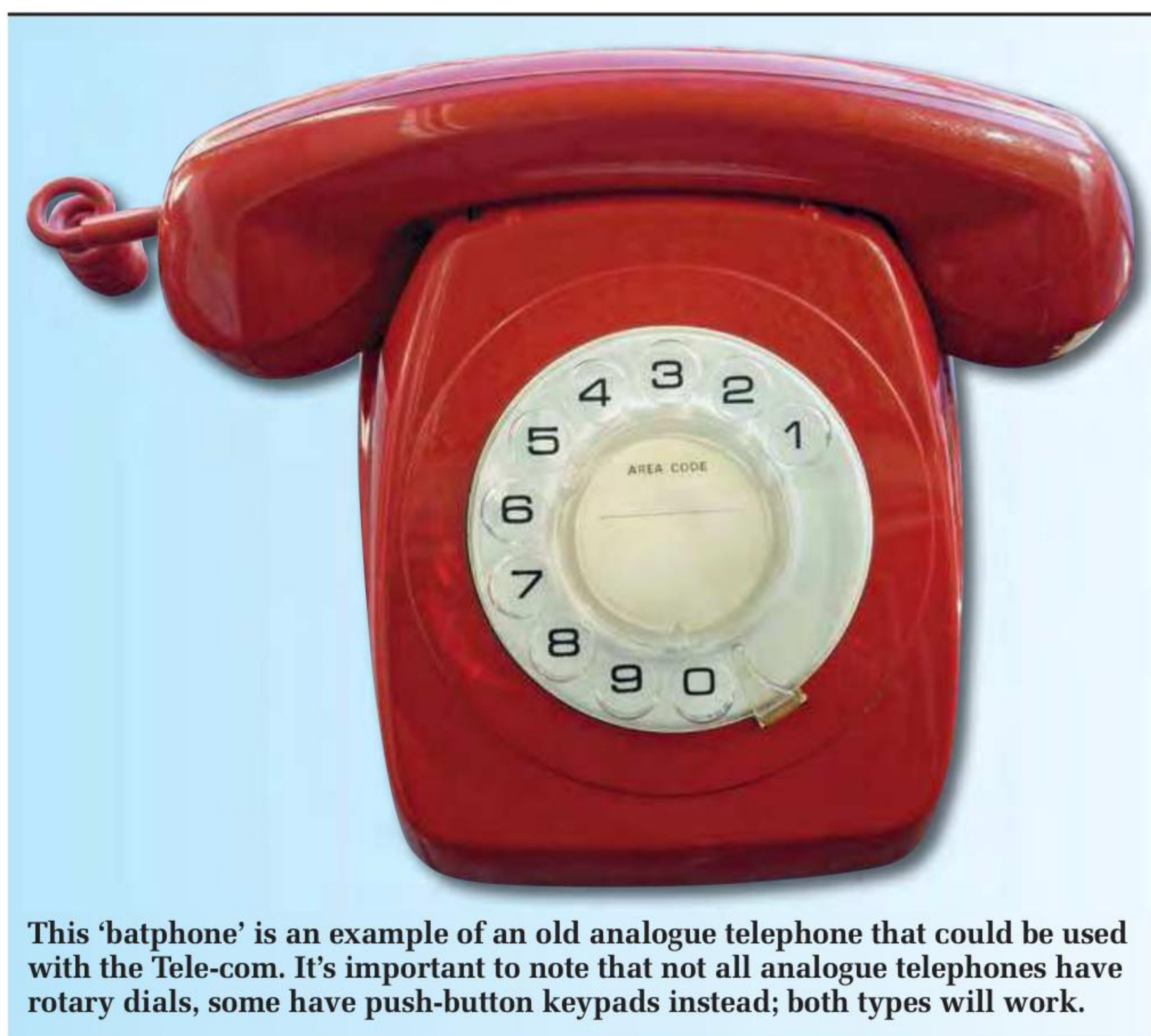
When the called telephone is taken off-hook to answer, current will flow through the LED in the optocoupler associated with the called telephone, thereby initiating ring trip. Ring trip can take place during the ringing period or the silent period.

Initiating a call

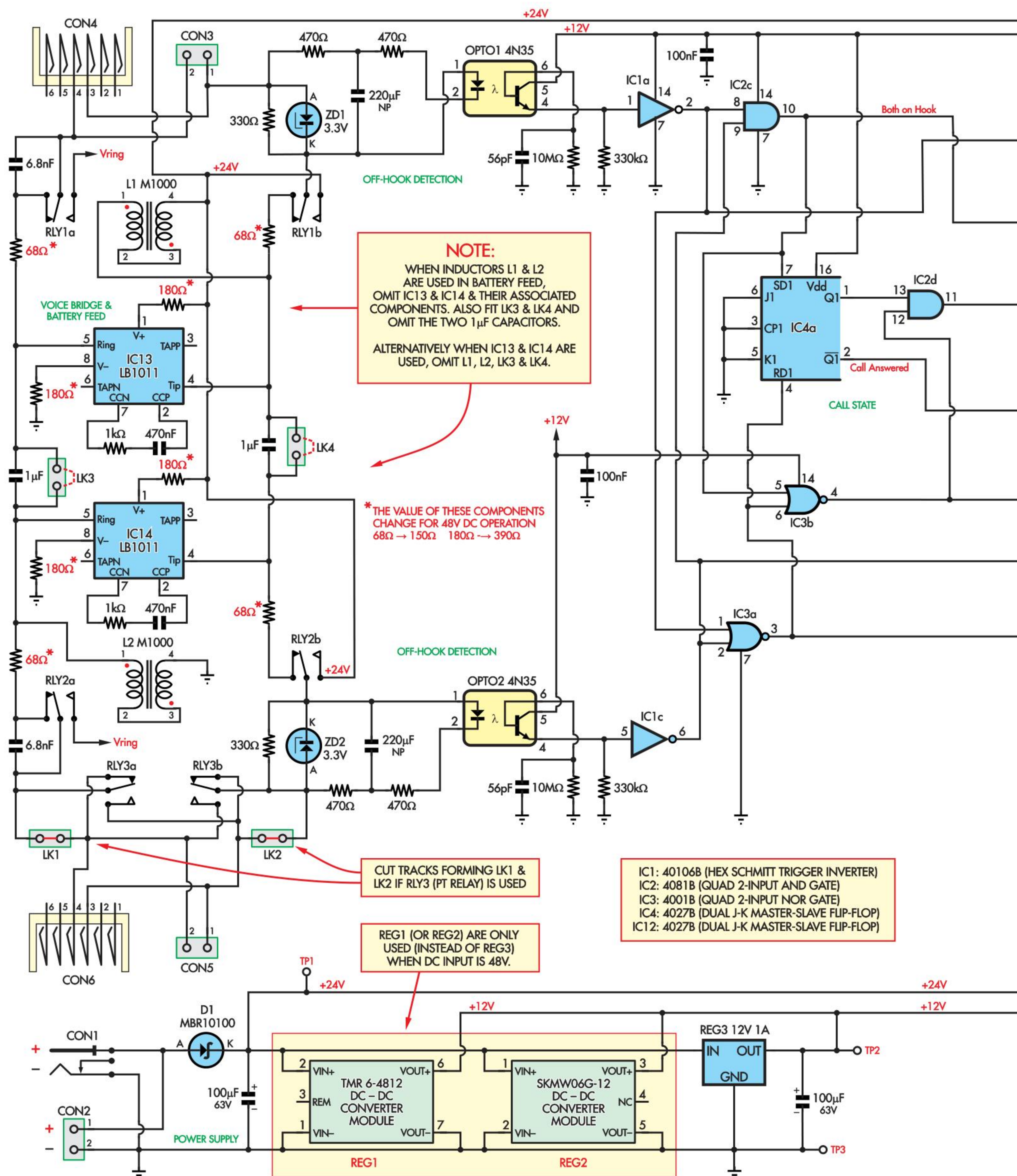
The following description refers to a call initiated by a telephone connected to CON4 (or CON3) when the board is constructed with the inductor-

based battery feed (see below). Note that in this case, the $1\mu\text{F}$ capacitors in the feed bridge are replaced by links (LK3 and LK4).

When the telephone is taken off-hook, 24V DC flows through transformer L1 (wired as an inductor) and the 68Ω resistor, the normally-closed



This 'batphone' is an example of an old analogue telephone that could be used with the Tele-com. It's important to note that not all analogue telephones have rotary dials, some have push-button keypads instead; both types will work.



OzPLAR Telephone Intercom – Battery Feed, Logic and Power

contact of relay RLY1b, the LED in OPTO1, the telephone and back to ground via the normally-closed contact of relay RLY1a, the 68Ω resistor, LK3, and transformer L2 (also wired as an inductor).

The off-hook condition detected by OPTO1 results in a high level at the input of schmitt-trigger inverter

IC1a. The resulting low output on pin 2 starts the calling process through the combined action of AND gate IC2c and NOR gate IC3a.

The Q1 output on pin 1 of J-K master/slave flip-flop IC4a is preset high in the idle state. With both inputs of IC2d now high, its output at pin 11 also goes high. This feeds into both

IC2a and IC2b; however, the low level on IC2b pin 5 prevents RLY1 from operating. Since both inputs of IC2a are high, the output will also be high, which results in RLY2 operating.

The RLY2 contacts disconnect the battery feed from the telephone at CON6 (CON5), and instead apply +24V to one leg of the line and the

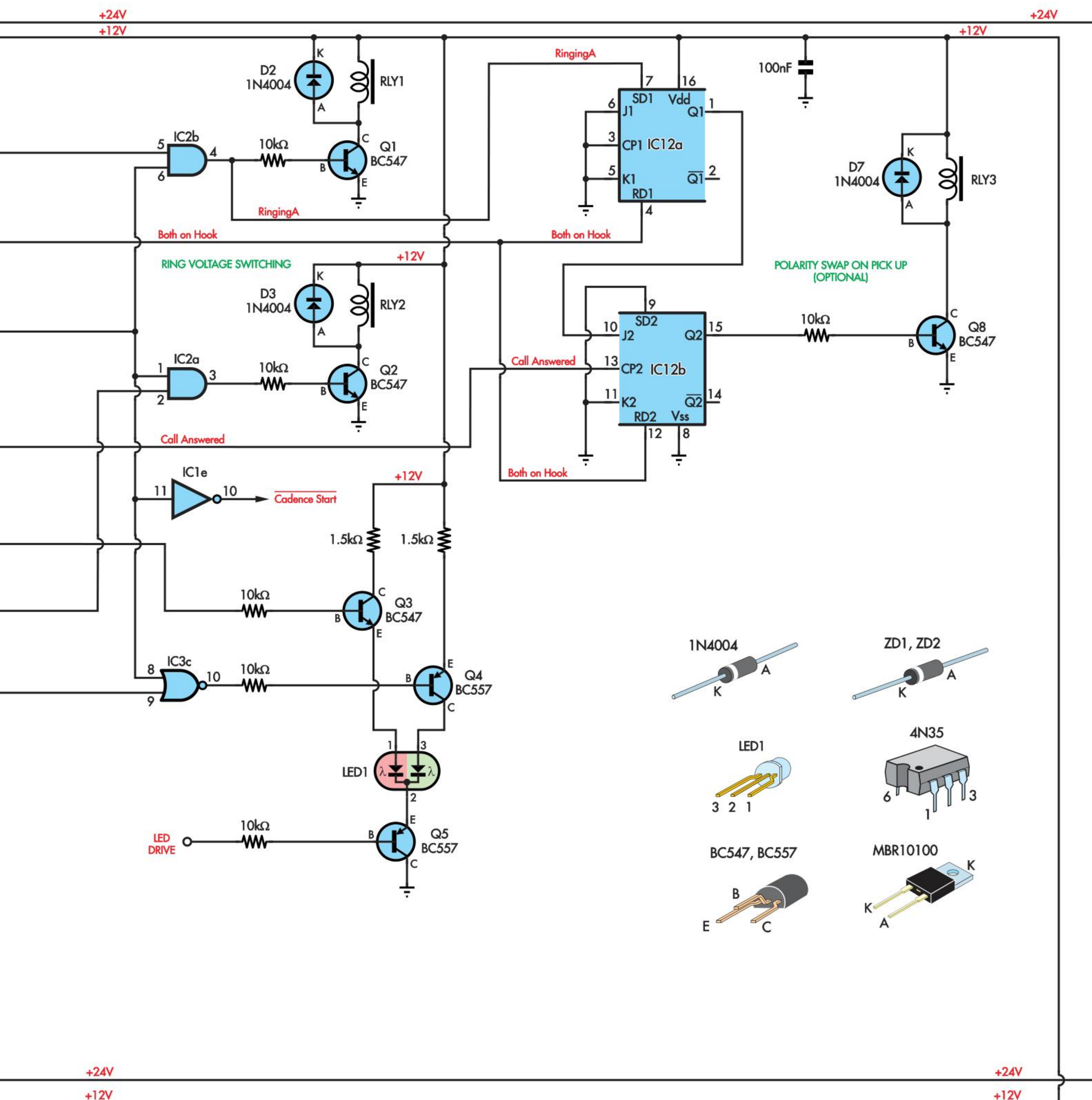


Fig.1: the Tele-com circuit, minus the ring and cadence-generating circuitry, shown separately in Fig.2. The telephones plug into the sockets at the top and bottom of the left-hand side. The circuitry between them mainly involves supplying current to the phones and ensuring that voice signals pass between them. To the right, we have logic to detect when a phone is picked up and either ring the other phone or ‘answer the call’ if the other has already been picked up.

ringing (V_{RING}) signal to the other, causing this telephone to ring.

At the same time, the high level at the output of IC2d (pin 11) is inverted by IC1e, sending the Cadence Start line low to enable the crystal oscillator and the logic controlling the ringing inverter, shown in Fig.2.

‘Cadence’ refers to the timing of the ring bursts and silent periods.

4060 counter IC5 is held in reset at idle, but now commences oscillating. The reset signal is also removed from decade counter IC6, flip-flop IC4b and

the cadence generator decade counters IC7 and IC8.

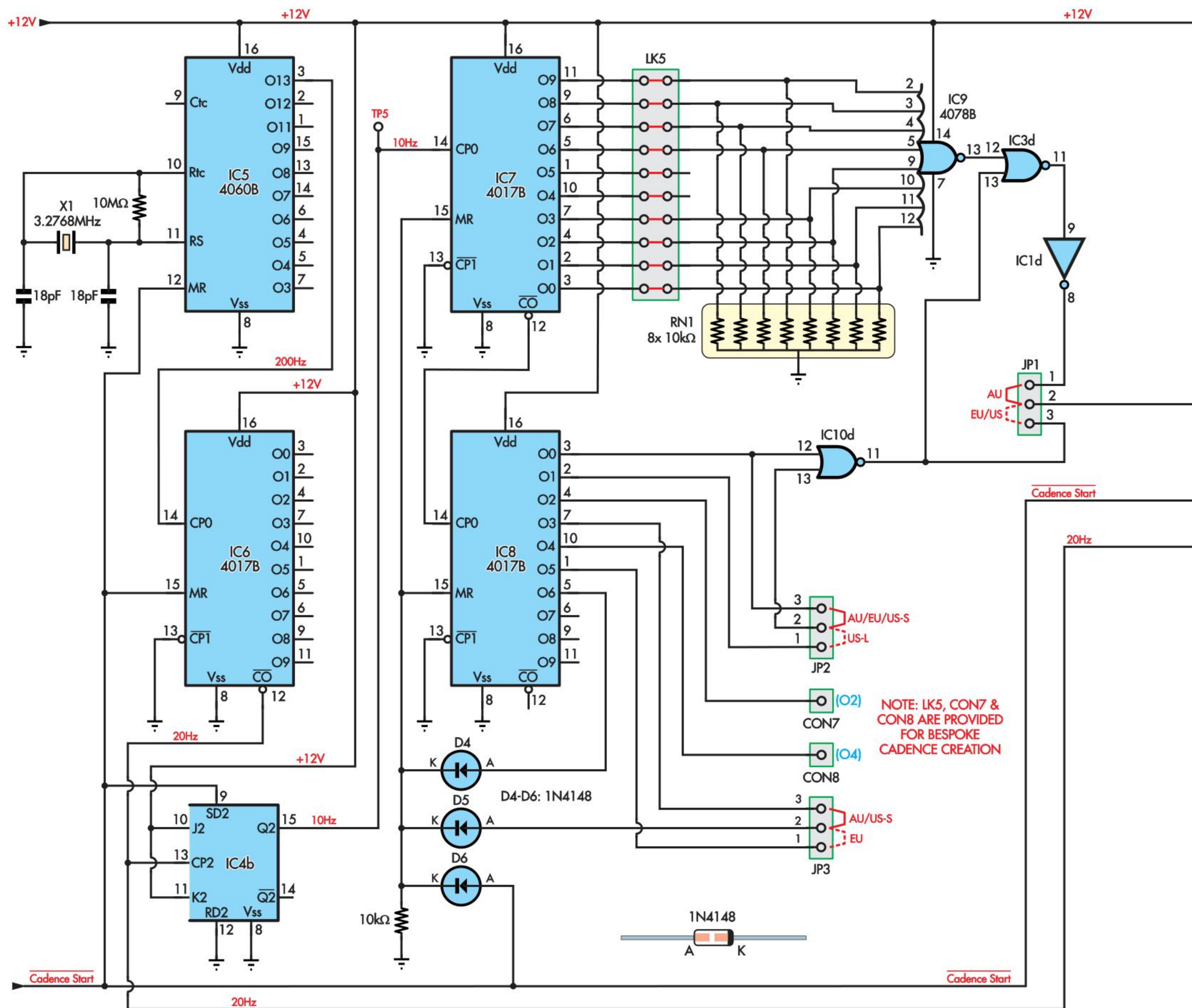
Cadence Start is also presented to pin 8 of NOR gate IC10c, which in conjunction with IC7 and IC8, controls the cadence of the AC ringing signal (for example, when set for Australia, producing the traditional ring...ring ring... sound).

The 3.2768MHz crystal oscillator based on X1 has its frequency divided by IC5 to produce 200Hz at its O13 output. This is divided by IC6 to produce the 20Hz alternating signal required for the efficient operation

of electromagnetic telephone bells. This signal is also fed to the input of IC1b and IC10a, and in conjunction with the cadence signal at the output of IC1f, enables the ringing inverter.

The 20Hz signal at IC6 pin 12 is halved by IC4b to produce the 10Hz clock signal for IC7. The outputs of IC7 go high sequentially, producing a one-second clock signal to feed IC8.

The outputs of the 4017 decade counters, IC7 and IC8, are encoded in a manner that determines the on-off cadence pattern sent to the ringing inverter – see Fig.3 for details.



OzPLAR Telephone Intercom – Cadence Logic and Ring Voltage Generator

Regardless of the cadence selection, the instant Cadence Start goes low, the ringing inverter is enabled, and the called telephone commences ringing.

When the inputs to NOR gate IC10c are both low, its output is high. This is inverted by IC1f and fed to one input of gates IC10a and IC10b. The second input of these two gates alternates high or low following the 20Hz drive signal, while IC1b ensures that both MOSFET drive signals are complementary (ie, alternately phased).

MOSFETs Q6 and Q7 alternately switch the 12V DC supply through each primary winding of transformer T1. Due to the step-up ratio, an alternating voltage in the order of 120V peak-to-peak is produced in the secondary. PTC thermistor PTC1 provides over-current protection, while the 2.2kΩ

resistor provides a degree of clamping of the output voltage, should there be no load connected.

While the ringing inverter is operating, the 6.8nF capacitor, normally bypassed by RLY2a, feeds a tiny amount of the ringing voltage back to the calling telephone, serving as the ringtone.

Cadence generation and selection

Jumpers JP1, JP2 and JP3 allow easy selection of the ‘ring-ring-pause’ (400ms on, 200ms off, 400ms on, two seconds off) cadence familiar to Aussies, our Kiwi neighbours and the UK.

Other options are for the European cadence (one second on, four seconds off) and the two common versions of the US cadence (two seconds on, four seconds off and one second on, two seconds off), commonly referred to as ‘US Long’ and ‘US Short’ respectively.

There are many cadences globally, and they’re documented in the ITU PDF at: <https://bit.ly/pe-oct22-itu>

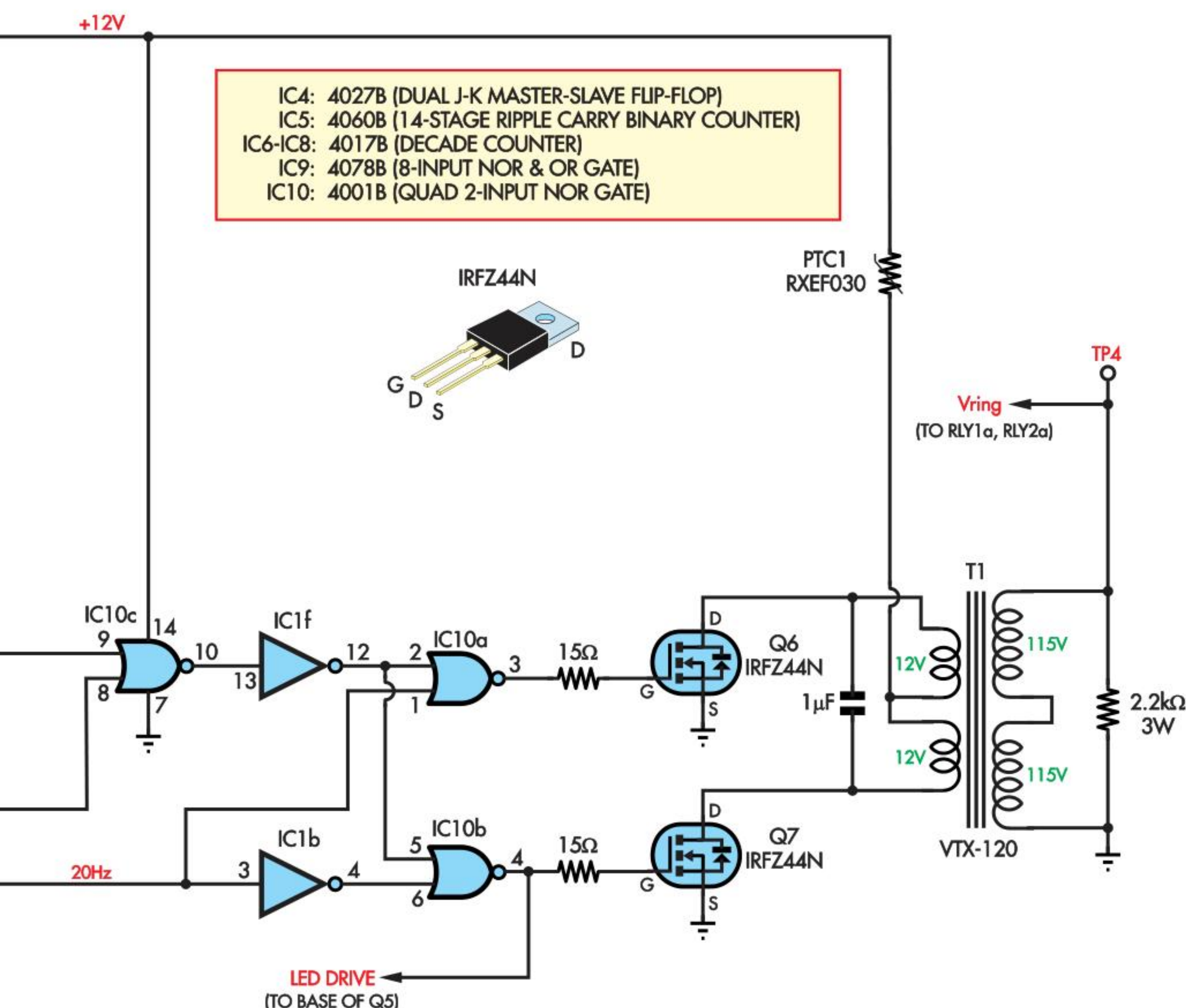
Let’s assume the board is set up for AU cadence.

When Cadence Start goes low ($t=0.0s$), the counter in IC6 is released from its reset state and commences counting. At that same instant, the reset signal is removed from IC4b, IC7 and IC8 in readiness for clock ticks to arrive.

Having just been released from reset, output O0 of IC7 is high. Pin 12 of NOR gate IC9 is thus high, so its output is low.

O0 of IC8 is also high. This feeds to pins 12 and 13 of IC10d via JP2 pins 2 and 3, and thus pin 11 of IC10d is low.

For a brief period, the inputs of NOR gate IC3d are both low, so its output is high. IC1d again inverts this



◀ Fig.2: the rest of the circuitry which wouldn't fit on Fig.1. At left is the cadence-generating circuitry; the outputs of IC7 go high in sequence at 100ms intervals, while those of IC8 go high at one-second intervals. These signals are fed into a series of logic gates depending on the position of jumpers on JP1-JP3 and possibly LK5, resulting in a signal at output pin 10 of IC10c that indicates whether the phone should be ringing or not at any given moment. This is then converted into an AC voltage sufficient to ring a telephone by MOSFETs Q6 and Q7 and transformer T1.

to a low signal and this is fed via JP1 pins 1 and 2 to pin 9 of IC10c. The ringing inverter is enabled and it generates the 20Hz alternating voltage to ring the telephone.

100ms later, counter IC7 increments, sending O1 high, then on to

O2 and O3. The ringing generation is maintained by linking these outputs to IC9's inputs, resulting in a continuous on-period of 400ms.

Outputs O4 and O5 of IC7 are not connected, so for those two 100ms ticks, IC9 has all low levels on its

inputs, its NOR output goes high, so the ringing inverter is disabled for 200ms.

For the final 400ms of the first one second of cadence, IC7 outputs O6-O9 are clocked sequentially high, and the ringing inverter is enabled again.

At $t=1.0s$, IC7 resets and IC8 increments, sending its O0 output low. IC10d now prevents further signals from IC7 and IC9 from enabling the ringing inverter for the remaining period of the selected cadence pattern up until the instant output O3 of IC8 goes high, at $t=3.0s$. This signal, via JP3 pins 2 and 3 and diode D5, resets IC7 and IC8 and the cadence pattern repeats.

The US and EU cadences are simpler, as IC9 and its related logic are no longer in play. JP2 instead directs either O0 or O1 of IC8 via IC10d and JP1 to the ringing inverter's drive logic, thereby enabling the inverter which produces ringing for either one second (EU, US-S), or two seconds (US-L).

The silent period for both AU and US-S cadence is terminated after three seconds, when output O3 of IC8 goes high, as explained earlier. The silent period for the EU cadence is terminated after five seconds, via JP3 pins 1 and 2 and diode D5. The silent period for US-L cadence is terminated after six seconds, when output O6 of IC8 goes high, via diode D4.

Bespoke cadence creation is beyond the scope of this article, but any combination of 100ms on/off times can be created by mating the required O outputs of IC7 with up to eight inputs of IC9. This is via the pins of JP1-JP3, CON7, CON8 and LK5 as described at: <https://bit.ly/pe-oct22-bcc>

Called party answers (ring trip)

The 20Hz ringing voltage is superimposed upon the 24V DC supply. This ever-present DC allows the LED in the optocoupler associated with CON6 (or CON5) to conduct when the handset is lifted to answer a call. That's regardless of whether it happens during a ringing or silent period.

When ringing is present, the LED is prevented from conducting by the low-frequency filter formed by the two 470Ω resistors and the 220μF NP capacitor.

The 10MΩ resistor provides a slight 'off' bias to the base of the optocoupler transistor, while the 56pF capacitor minimises noise pickup in the base connection. The 330kΩ resistor acts as the emitter load for the optocoupler output transistor.

When answered, the optocoupler transistor turns on, and the resulting low at the output of inverter IC1c pin 6 causes NOR gate IC3a pin 3 to go

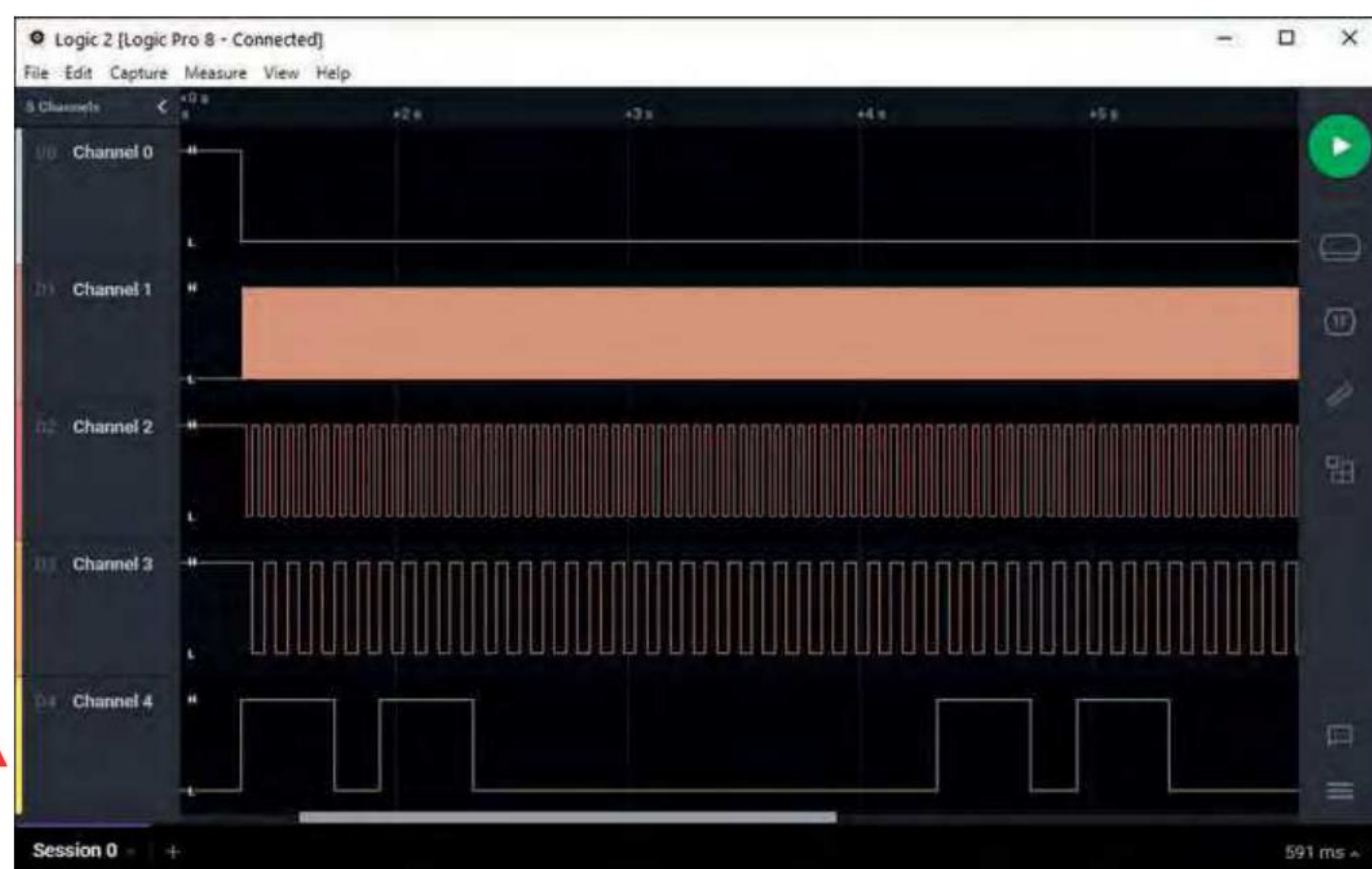


Fig.3: this logic analyser screenshot demonstrates how the cadence generation circuitry works. Ch0 is the Cadence Start line (active-low), Ch1 is the 200Hz square wave at the O13 output of IC5, Ch2 is the 20Hz signal from pin 12 of IC6, Ch3 is the 10Hz signal at TP5 feeding into pin 14 of IC7, and Ch4 is the resulting cadence signal at pin 10 of IC10c (inverted so it is active-high). This shows the AU cadence.

high, thereby resetting flip-flop IC4a, causing its Q1 output to go low and RLY2 to release. The low on IC4a Q1 also causes the Cadence Start line to go high, holding all the counters reset and disabling the ringing inverter.

The release of RLY2 restores the change-over contacts to normal, thus connecting the called telephone to the battery feed and establishing a speech path between the two telephones.

One party clears

If we assume the telephone at CON4 (or CON3) hangs up first, the output of OPTO1 goes low and pin 2 of IC1a goes high. IC3a's output goes low, removing the reset on IC4a, but the flip-flop's outputs remain unchanged in the absence of any other stimulus.

If this telephone again goes off-hook before the other telephone hangs up, the reset on IC4a is once more asserted, but again there is no change of state in its outputs, so the speech path remains connected.

Both parties clear

If the telephone at CON6 (or CON5) hangs up after the other telephone goes on-hook, both of the inputs to IC2c become high, causing its output to go high, setting the flip-flop in IC4a and restoring all circuitry to the idle state in readiness for the next call.

Indicator LED

The bi-colour LED (LED1) displays the various phases of a call. At idle,

driver transistors Q3 (red) and Q4 (green) are both off, preventing both LEDs from illuminating, despite Q5 being on at this time.

When a telephone is being called, both Q3 and Q4 are fully on while Q5 switches alternately on and off in response to the 20Hz LED drive signal, resulting in both red and green LEDs following the ring cadence.

When a call is in progress, both telephones are off-hook. The green LED is illuminated due to the high on the output of IC3c forcing Q4 to conduct, while the low on the output of IC3b holds the red LED off. These two gates toggle when only one party has hung up, resulting in a steady red LED to indicate a possible fault condition – see the troubleshooting section below.

Feeding power to the phones

The *Tele-com* can be configured to use an inductor-based battery feed, as shown in Fig.4, where a 24V DC supply is fed to both legs of the line via inductors L1 and L2. Since the total available current must be shared between both telephones, the current to each telephone is dependent mainly upon line length, ie, the shortest line gets the most current.

The two 1 μ F capacitors shown on the circuit diagram are omitted and replaced by links in this case. Tests show that good speech is possible with line lengths up to 500m or more in this configuration – quite adequate for most situations.

Provision has also been made to replace the inductor-based battery feed with an electronic battery feed using special 8-pin ICs – see Fig.5. The use of two such devices allows the implementation of what's known as a Stone Bridge, such that the transmitter current supply to the two telephones is separate and determined only by individual line lengths.

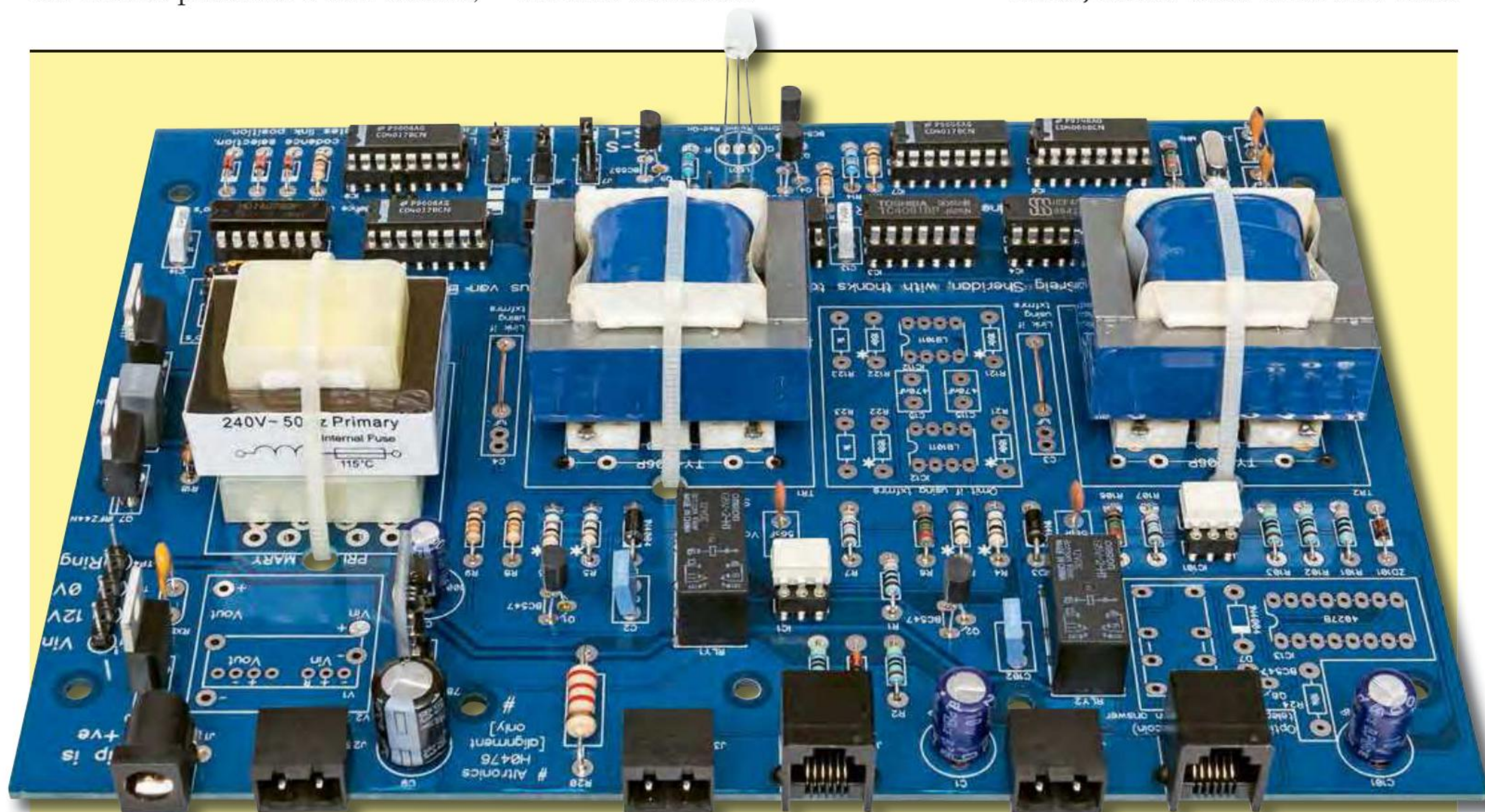
In Fig.5, the electronic battery feed ICs are depicted as individual inductors designated IC13 and IC14.

The electronic battery feed device was designed by AT&T with the part number LB1011. It is now obsolete and available only from electronics surplus component suppliers (eg, via eBay). It simulates two separate inductors having very high impedances at voice frequencies.

When IC13 and IC14 are installed in place of inductors L1 and L2, the two 1 μ F capacitors need to be fitted to the board. These capacitors provide speech coupling between the two telephones connected to CON4 (or CON3) and CON6 (or CON5). In this configuration, the maximum current in each telephone circuit is approximately 36mA, so line lengths of several kilometres are possible.

Optional reversal on answer

To allow this *Tele-com* to work with public (coin) telephones that require a line reversal on answer, the polarity of the line to CON6 (or CON5) can be made to reverse when



This is the finished *Tele-com* PCB without the optional IC-based battery feed, 48V power input components or 'polarity reversal on answer' feature.

the telephone at CON4 (or CON3) answers a call. This means that the public telephone must be connected to CON6 (or CON5).

Two flip-flops (IC12a and IC12b) are interconnected to provide this function. With both telephones on-hook, both flip-flops are held reset. When either phone goes off-hook, the reset signal is removed.

If the telephone connected to CON6 (CON5) is the caller, the output of IC2b presents a high to pin 7 of IC12a, setting this flip-flop. The high on the Q1 output is tied to the J2 input of IC12b, and with J2 high and K2 low, an answer signal from IC4a pin2 will toggle IC12b and set output Q2 high. NPN transistor Q8 then switches on and RLY3 operates, reversing the line polarity of CON6 (CON5).

Should the telephone connected to CON4 (CON3) initiate a call, pin 7 of IC12a will not be set, and the J2 input to IC12b will remain low; therefore, the outputs of this flip-flop will not change state when the answer signal from IC4a pin 2 is applied to pin 13 of IC12b. RLY3 will remain in the unoperated condition and the line polarity will not be reversed.

Flip-flops IC12a and IC12b will reset only when both telephones are restored on-hook, causing RLY3 to release.

Power supply

The power supply takes an incoming +24V DC through reverse-polarity protection diode D1, and REG3 supplies +12VDC to power the logic, relays and the ringing inverter. A linear 7812 regulator was tried during the design phase, and replaced with a switchmode equivalent due to excessive heat dissipation, particularly when ringing.

For an application where a higher ringing duty cycle is anticipated, or the *Tele-com* is to be powered from batteries, a switch-mode equivalent should be used instead (eg, our August 2021 design, see the *Switch-mode Replacement for 78xx Regulators* project).

If a 48V DC supply is to be used, REG3 is omitted and instead, a MeanWell (REG2) or Traco (REG1) DC-DC converter is fitted to accept the higher input voltage and step it down to +12V.

Construction

The *Tele-com* project is built on a double-sided PCB coded 12110121, which measures 200.5 x 143mm and is available from the *PE PCB Service*. Start by giving the PCB a quick visual inspection for any obvious damage (although that is quite unusual). Use

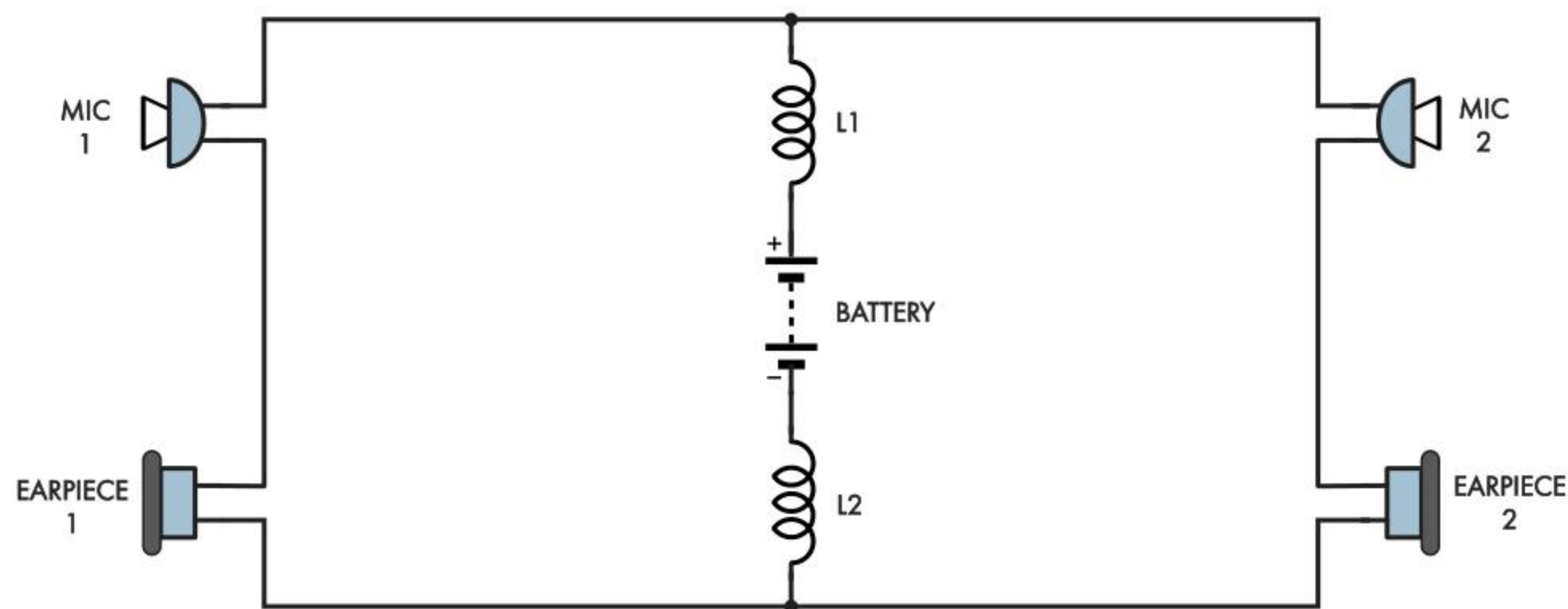


Fig.4: this shows the simplest way to power two telephones. Two high impedance inductors allow DC current to supply the transmitter while blocking AC signals through the low resistance of the battery. However, the proportion of the available current to each telephone is dependent upon the length of both lines and a very long line may reduce the current to an unworkable level.

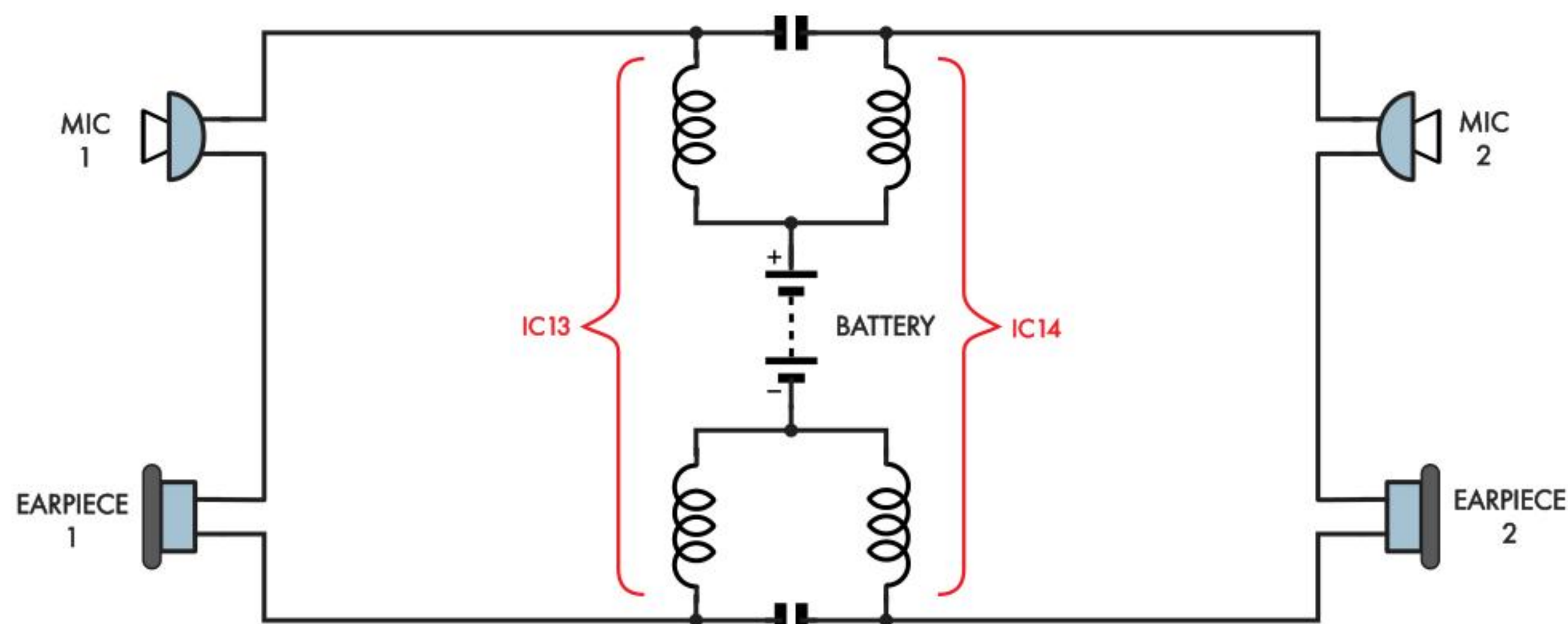


Fig.5: this is a more complicated battery feed scheme known as a Stone Bridge which uses virtual inductors to feed DC current to each telephone independently, with capacitors coupling speech signals between them. It can handle very long lines over 1km in length. The virtual inductors are contained in a special IC available via eBay or suppliers of obsolete components

the PCB overlay diagram (Fig.6) as a reference during construction, but note that there are a few different options that affect which components are fitted.

If you are planning to build the *Tele-com* with a custom cadence, you will need to cut some tracks on the underside of the board below LK5, separating the rows of pads on either side. Take care when cutting these tracks, as there is very little separation between the two rows of pads.

If you plan to add the Reversal on Answer relay RLY3, there are two tracks noted with the word 'cut' on the underside of the board – they are also indicated on the component overlay as two short lines joining two of the centre pads below RLY3.

In both cases, if cutting, check with a continuity tester to ensure that the tracks have been completely separated before continuing.

The six mounting holes in the board fit mounting posts in the PacTec LH96-200 enclosure. If you're using that case, you can jump to the board assembly.

If you're building into the Altronics H0476 instead, there are two holes near the rear (connector) edge that align with two mounting posts under the board. They're marked on the component overlay (Fig.6) with '#' marks.

Temporarily screw the board to these, as this will align the board correctly within the box, then use the mounting holes in the four corners as a template to drill holes that will support the board. Remove the temporary screws and continue with the assembly.

Breaking with tradition, mount the connectors first and ensure these all align and project through the rear panel. The pads for the power and screw connectors have been drilled oversize to provide a little extra wriggle room.

Continue with the resistors and other low-profile components like the axial diodes and the crystal. If you're building it with the inductor-based battery feed, don't forget to replace the 1µF capacitors to the right-hand side of the transformers with links.

Also, if you're building for a 48V supply, note that the resistors marked on the overlay with an asterisk have different values for 48V. See the parts list for details.

You can then install the SIL resistor array if you will be using the custom cadence feature, with its dot at the end shown in Fig.6 and on the PCB silkscreen.

Now add the capacitors, starting with the smallest ceramic types and

Parts List – Tele-com

- 1 double-sided PCB coded 12110211, 200.5 x 143mm, available from the PE PCB Service
- 1 PacTec LH96-200 ABS instrument case or equivalent, 260x180x65mm [Altronics [H0476](#), RS [291-4169](#), Mouser [616-74213-510-039](#)]
- 1 set of front and rear 3D-printed panels (size to suit case, see: www.thingiverse.com/thing:4922521)
- 1 24V DC 2A power supply [Altronics [M8970D](#), WES [SMP2500-24RLP](#) + [ACL104-075](#)]
- 1 3VA 12+12V PCB-mount mains transformer (T1) [Altronics [M7024A](#) ①]
- 2 600Ω:600Ω isolation transformers ② (L1, L2) [Altronics [M1000](#) or Triad [TY-305P/306P/400P](#)]
- 2 Omron G5V-2-H1DC12 12V DC coil relays or equivalent (RLY1, RLY2) [Altronics [S4150](#)]
- 1 3.2768MHz crystal resonator (X1)
- 1 RXEF030 300mA hold current PTC thermistor (PTC1) [element14 [1175861](#), Mouser [650-RXEF030](#), Digi-Key [RXEF030-ND](#)]
- 1 10kΩ 9-pin, 8-element SIL resistor network (RN1; only needed for bespoke cadence) [element14 [9356819](#), Digi-Key [4609X-101-103LF-ND](#)]
- 1 PCB-mount barrel socket, 2.1/2.5mm inner diameter (CON1) [element14 [1854512](#), RS [805-1699](#)]
- 3 right-angle two-way pluggable headers (CON2, CON3, CON5) [Jaycar [HM3102](#) + [HM3122](#), Altronics [P2592](#) + [P2512](#), element14 [2527811](#) + [2527762](#)]
- 2 PCB-mounting 6P6C RJ12 sockets (CON4, CON6) [Altronics [P1425](#), Jaycar [PS1474](#), Würth [615006138421](#)]
- 2 1-pin headers (can be snapped from a longer strip) (CON7, CON8; only needed for bespoke cadence)
- 3 3-pin headers with shorting blocks (JP1-JP3)
- 1 2x10-pin header or header socket (LK5; only needed for bespoke cadence)
- 5 PCB pins (optional; for test points TP1-TP5)
- 12 M3 x 6mm panhead machine screws
- 6 6mm-long M3-tapped spacers
- 6 6mm-long 6G self-tapping screws (PacTec case only)
- 3 300mm-long 4mm-wide cable ties
- 5 14-pin DIL IC sockets (optional)
- 5 16-pin DIL IC sockets (optional)
- 1 12-pin snappable IC socket strip (optional, for OPT01-2)
- ① alternatives include RS [504-464](#), element14 [1712727](#) (Vigortronix VTX-120-003-612), Mouser [553-FS24-100](#) (Triad FS24-100) and [838-3FD-324](#) (Tamura 3FD-324), RapidOnline [88-3883](#) (Vigortronix VTX-120-3803-412)

Semiconductors

- 1 40106B or 74C14 hex inverter IC, DIP-14 (IC1)
- 1 4081B quad 2-input AND gate IC, DIP-14 (IC2)
- 2 4001B quad 2-input NOR gate ICs, DIP-14 (IC3, IC10)
- 1 4027B dual J-K flip-flop IC, DIP-16 (IC4)
- 1 4060B 14-stage ripple-carry binary counter IC, DIP-16 (IC5)
- 3 4017B decade counter/divider ICs, DIP-16 (IC6-IC8)
- 1 4078B 8-input OR/NOR gate IC, DIP-14 (IC9)
- 2 4N35 optocouplers, DIP-6 (OPT01, OPT02)

- 1 Switchmode 12V 1A regulator ③ (Pololu D24V10F12 or the PE August 2021 design: *Switchmode Replacement for 78xx Regulators*) (REG3)
- 3 BC547 100mA NPN transistors (Q1-Q3)
- 2 BC557 100mA PNP transistors (Q4, Q5)
- 2 IRFZ44N 55V, 49A N-channel MOSFETs (Q6, Q7)
- 1 3-pin bicolour/tricolour (red/green) common cathode 5mm LED (LED1) [Jaycar [ZD0252](#)]
- 2 3.3V ±5% 1W zener diodes (eg, 1N4728A) (ZD1, ZD2)
- 1 MBR10100 100V 10A schottky diode, TO-220 (note: not dual [CT] version) (D1)
- 2 1N4004 400V 1A diodes (D2, D3)
- 3 1N4148 or equivalent small signal diodes (D4-D6)

Capacitors

- 2 220μF 10V non-polarised (NP/BP) electrolytic [Altronics [R6600A](#) or Mouser [667-ECE-A1AN221U](#)]
- 2 100μF 63V electrolytic
- 1 1μF 100V MKT
- 3 100nF X7R ceramic
- 2 6.8nF 63V MKT
- 2 56pF 50V NP0/C0G ceramic disc
- 2 18pF 50V NP0/C0G ceramic disc

Resistors (all ¼W 5% metal film unless otherwise stated)

- | | | |
|---------|---------------|---------|
| 3 10MΩ | 1 2.2kΩ 3W 5% | 2 330Ω |
| 2 330kΩ | 2 1.5kΩ | 4 68Ω ③ |
| 6 10kΩ | 4 470Ω | 2 15Ω |

Additional parts for IC-based battery feed (exclude parts marked ② above)

- 2 AT&T/Lucent LB1011 battery feed ICs, DIP-8 (IC13, IC14) (eBay or one of the suppliers listed at: www.digipart.com/part/LB1011AB)
- 2 8-pin DIL IC sockets (optional)
- 2 1μF 250V MKT capacitors
- 2 470nF 63V MKT capacitors
- 2 1kΩ ¼W 5% resistors
- 4 180Ω ¼W 5% resistors ③

Additional parts for reversal on answer

- 1 Omron G5V-2-H1 12V DC coil telecom relay or equivalent (RLY3) [Altronics [S4150](#)]
- 1 16-pin DIL IC socket
- 1 4027B dual J-K flip-flop IC, DIP-16 (IC12)
- 1 BC547 100mA NPN transistor (Q8)
- 1 1N4004 400V 1A diode (D7)
- 1 10kΩ ¼W 5% resistor

Additional parts for 48V DC supply (exclude parts marked ③ above)

- 1 Traco TMR 6-4812 48V DC to 12V DC converter (REG1) [Mouser [495-TMR-6-4812](#)] OR
- 1 Mean Well SKMW06G-12 48V DC to 12V DC converter (REG2) [Mouser [709-SKMW06G-12](#)]
- 4 390Ω ½W 5% metal film resistors
- 4 150Ω ¼W 5% resistors

then working your way up to the bigger ones.

Confirm the polarity of the two electrolytics at the top right of the board and double-check that you have non-polarised electros adjacent to the telephone connectors. Now is also a good time to fit the PTC thermistor.

The LED should be soldered at full extension onto the board if it's to go into the PacTec case; however,

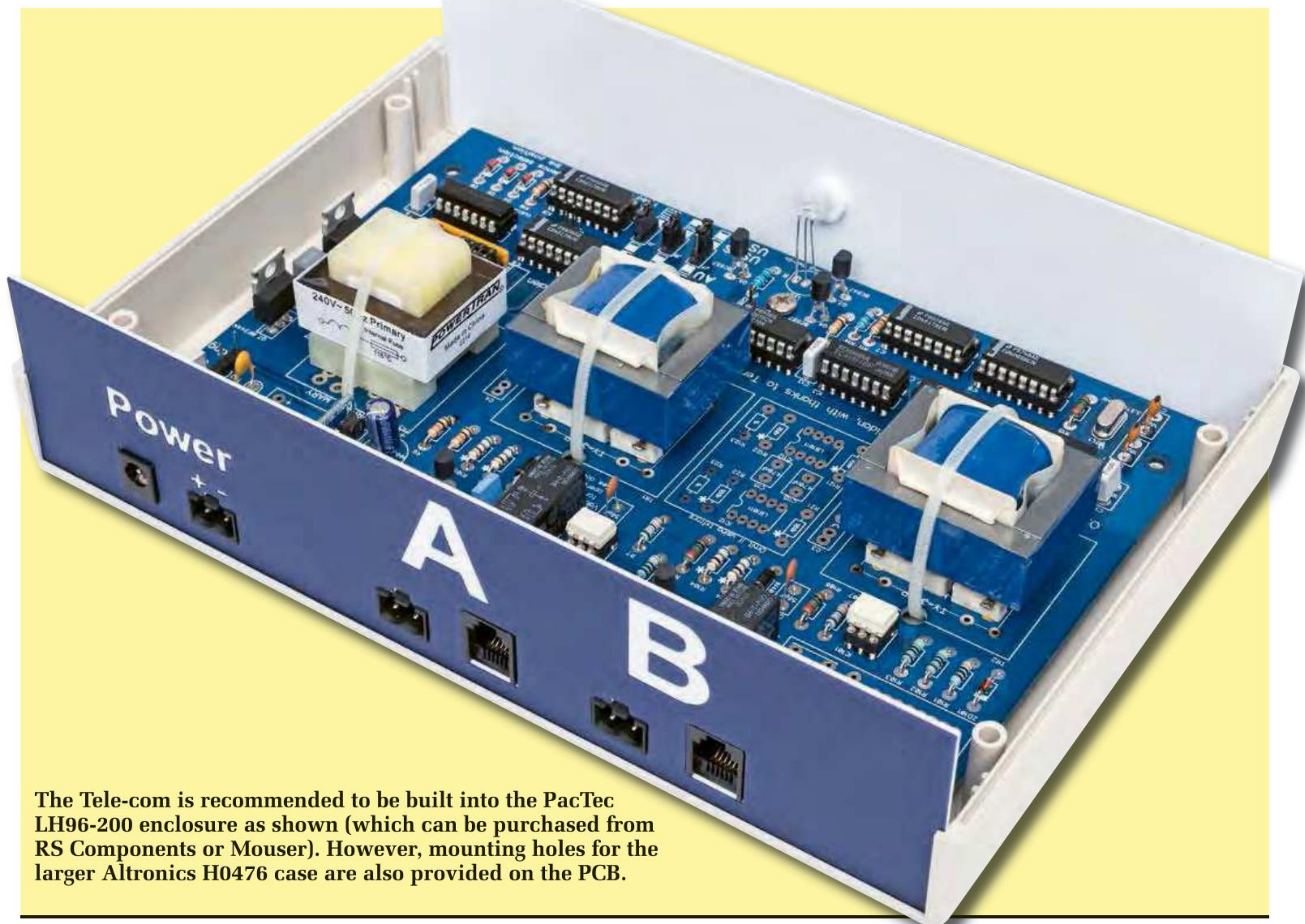
you'll need to add some short flying leads for it to reach the panel in the Altronics case.

Add the remaining active components (ICs, regulators, optos and transistors), plus the TO-220 package diode, ensuring all the ICs have pin 1 on the right-hand side, and the TO-220 devices all face left (with their metal tabs to the right). The use of IC sockets is recommended

(including the optos), but check that +12V and GND (0V) are present on the correct pins before inserting ICs in their sockets.

The optional test point PCB stakes and jumpers can be fitted next, then the relays, which must be oriented as shown in Fig.6.

If you need LK5 and haven't already fitted it, do so now, along with the headers for jumpers JP1-JP3. Follow



The Tele-com is recommended to be built into the PacTec LH96-200 enclosure as shown (which can be purchased from RS Components or Mouser). However, mounting holes for the larger Altronics H0476 case are also provided on the PCB.

with the switchmode DC-DC converter (REG1 or REG2) if you will be using a 48V supply.

Finally, fit the transformers one by one. Place them, then wrap a cable tie around them firmly before soldering their pins. Take extra care if you're using Tamura or Triad transformers for T1, as these can go into the board either way, but only one way is correct.

Their 'mains' winding faces the rear panel connectors. The formers of both have pin numbers moulded into them, with the '1-2-3-4' side being the mains side.

Troubleshooting

There isn't much to testing it. Plug in a couple of known-good telephones, apply the appropriate DC voltage and check that it works as expected.

If you encounter problems, the nature of the fault should tell you which part of the circuit requires attention, but always start by confirming that the 'Vin' voltage (24/48V) and 12V rails are present.

You can sometimes isolate faults by touching the top of each IC, where any heat detected indicates a faulty device (CMOS ICs generally don't produce significant heat unless they are faulty). If you've done this before,

you probably know to apply a little saliva to your fingertip first to prevent burning yourself.

No sidetone

You should only connect known-good telephones to the *Tele-com*. You should hear 'sidetone' if they are working correctly – some amount of your own voice is audible in the receiver. The easiest way to check for sidetone is to gently blow into the transmitter – you should hear the resulting hiss in the receiver.

If sidetone is absent in either telephone, start by checking that power is switched on and 24V (48V) is present on the board test pins. If the fault is not in the telephones, then check the wiring.

If one is working and the other not, follow the circuit with your multimeter and compare between the two channels until the fault reveals itself. Don't forget to swap the phones as a first check!

No ringing

First, check that jumpers JP1-JP3 are correctly set for one of the ring cadence patterns – follow the silk-screen legend on the board adjacent to these jumpers to select the cadence that you want.

If there's no ringing when the first telephone goes off-hook, then check the LED.

If the LED is not lit at all, first make sure that it is a common-cathode device and driver transistors Q3, Q4 and Q5 are fitted in their correct positions.

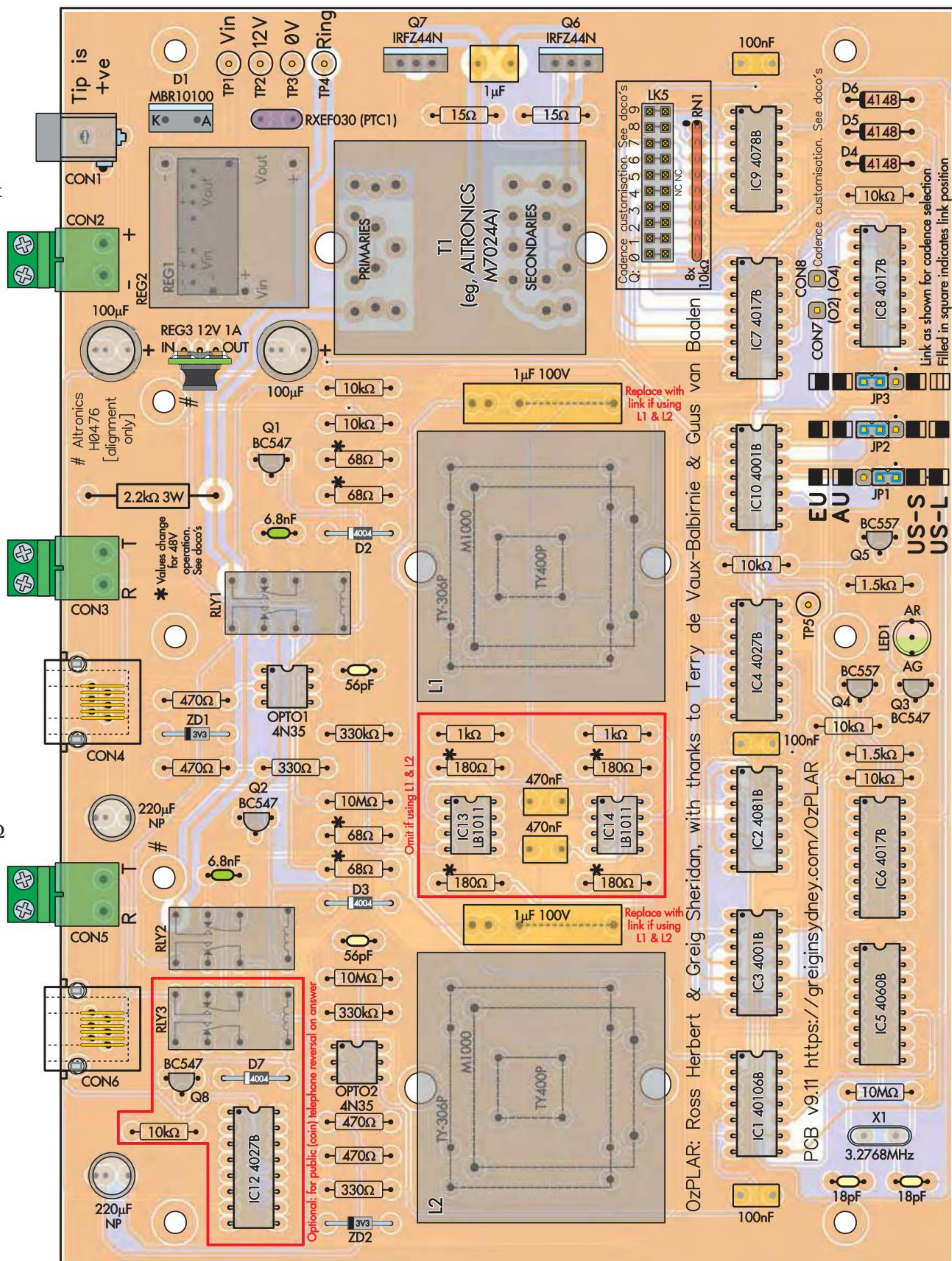
Briefly short pins 4 and 5 of OPTO1 or OPTO2. If that brings it to life, there's most likely a problem with the optocoupler or the components on the LED side of this device. Check that the 3.3V zener cathodes are both facing 'up', towards the rear panel.

If one of the relays operates when a telephone goes off-hook, that confirms that the main logic engine is functioning correctly. If neither relay operates, this narrows your focus to IC2-IC4 or the 12V rail.

If the LED is flashing, this confirms the oscillator and cadence components are working OK, suggesting you should check the MOSFETs and transformer. TP4 should have a pulsing 120V (approximately) alternating voltage on it, according to the selected cadence. Check also that the centre tap on the secondary of the transformer has +12V applied.

If the LED is lit but not flashing, check with an oscilloscope, logic probe, or the frequency range on your multimeter that TP5 (near the LED) is

Fig.6: assembly of the Tele-com is straightforward, but there are quite a few different options, some of which involve fitting different parts. So you won't necessarily install everything shown here. It's best to work out what you will or won't be mounting, and the components that might change in value, before you start. As you build the board, be careful to ensure that all the ICs, diodes, LED, optocouplers, transformers, transistors and polarised electrolytic capacitors are oriented correctly, as shown here. If using a 48V DC supply the four 180Ω resistors in the centre red box, and marked with an asterisk, are replaced with 390Ω resistors, while the 68Ω resistors marked with an asterisk become 150Ω.



fluctuating at 10Hz. If 10Hz is present, focus on IC7, IC8, the jumpers LK5, JP1 and JP2, diodes D4, D5 and D6, and the 10kΩ resistor immediately adjacent to these diodes.

If TP5 is not fluctuating at 10Hz, focus on the 3.2768MHz crystal, its loading caps, IC5, IC6 and IC4b.

Cadence problems

An unexpected cadence indicates an incorrect placement or missing jumper on LK5 or JP1-JP3. Try changing the jumpers to select an alternative cadence. If correct operation can be achieved when set to the EU

or US cadences but not the AU/NZ/UK ones, check that IC7 and IC9 are correctly seated. Check also that RN1 is not reversed and has the correct internal configuration, and one end pin is common.

If you've cut the tracks under LK5 in anticipation of using a custom cadence, make sure you have inserted links to replace the track segments which have been cut.

If problems remain, confirm that TP5 is pulsing at exactly 10Hz, re-check the board for any solder shorting adjacent IC pins and repeat the 'touch test' on the tops of the ICs.

Red LED on idle

If both telephones are on-hook and the LED is solid red, there's most probably a fault on the line or with one of the telephones, causing one not to be correctly seen as on-hook. Unplug each phone in turn to see if the LED extinguishes. If it does, the fault is in the wiring or telephone itself.

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TOUCHSCREEN AND REMOTE DIGITAL PREAMP WITH TONE CONTROLS



Our new *Digital Preamplifier*, introduced last month, combines high audio fidelity with convenience. It provides input switching, volume adjustment, bass/mid/treble controls via remote control and a colour touchscreen. It can be built as a standalone unit or integrated into a power amplifier. Having explained how it works, now we'll go through the construction and testing procedures.

This preamp brings analogue and digital circuitry together, giving the best aspects of both. It's a relatively simple design with excellent audio quality thanks to its analogue roots, but it avoids the complexity of the multiple, expensive ICs that would be needed for a purely digital design. It also avoids using mechanical parts that can wear out, like a mostly analogue design using a motorised potentiometer.

It has a good range of features, including a colour touchscreen interface, infrared remote support, a three-band tone control, a wide gain range and four stereo inputs.

Last month's article explained how all of this is achieved using a *Micro-mite LCD Backpack*, two quad low-distortion digital potentiometers and a handful of op amps. That article also included all the relevant performance data. Now that we've explained how it works, let's start on the assembly.

Construction

The main PCB overlay for the *Digital Preamp* is shown in Fig.7. This board is coded 01103191, measures 206 x 53mm (shown rotated) and is available from the *PE PCB Service* (September 2022).

As mentioned last month, we don't think the bypass relay (RLY4) and its associated components are necessary, so we have shown them greyed out. Instead, we recommend that you fit two wire links, shown in red. These let the signal pass to the output without RLY4 being fitted.

Assembly is pretty straightforward, with just two SMDs on the board (IC6

and IC7). Those parts are quite large, similar in size to a 14-pin DIP IC, and with widely spaced pins are not hard to solder.

Start with those two parts. Find their pin 1 markings and make sure they are oriented correctly, then apply flux paste to all the pads, rest the IC on top and tack one pin down. Check that all the pins are correctly aligned over their pads, then solder them. With enough good-quality flux paste on the pads, you can just load your iron with solder and drag it across the pins, and good joints will form.

Clean off the flux residue and carefully inspect the joins to ensure they have all formed properly (with the fillet touching both the pins and the pads) and that there are no bridges between adjacent pins. If you find bridges, apply more flux paste and use some solder wick and a fair bit of heat to remove the excess solder. Repeat the cleaning and inspection process to verify all is OK.

Now move on to the resistors, but leave off the larger 1W resistors for now. Note that two of the 100Ω resistors need ferrite beads slipped onto their leads before soldering – see Fig.7. Check each batch with a DMM set to resistance mode before fitting them to the board, and you can then fit those two wire links shown in red using resistor lead off-cuts.

Next, mount the diodes. All diodes are polarised, so check their cathode stripes against Fig.7 and the PCB silk-screen before soldering them in place. D1-D12 are BAT42 schottky types, while D13-D15 are standard 1N4148 signal diodes. Follow with zener diode ZD1.

Bend down REG4's leads by 90°, about 6mm from its body. Insert them into the PCB and then attach its tab to the mounting hole securely using a short machine screw, washer and nut. Once it's solidly attached and square, solder and trim its leads.

Now you can solder op amps IC1-IC5 to the board, ensuring they are oriented correctly. You can solder sockets if you prefer; they make swapping op amps easier but can lead to reliability problems long-term. Follow with bridge rectifier BR1, ensuring its + lead (usually longer) goes into the marked hole.

Install the two trimpots (both 500Ω) and then the three relays in a row, RLY1-RLY3. Ensure the stripes on the relays are positioned as shown, as it is possible to install them backwards.

Next, mount all the TO-92 package devices. These are transistors Q1-Q3 and Q5-Q7, plus regulators REG1-REG3. As there are five different device types in similar packages, be careful to check the markings so that you don't get them mixed up.

Now is a good time to fit all the ceramic capacitors (two different values) and MKT capacitors (five different values). Refer to Fig.7 and the PCB to ensure the right ones go in their correct locations.

Then fit the headers for links LK1-LK3, but do *not* insert the shorting blocks yet. Follow with the DC socket (if you plan to use it) and the 18-pin header, plus the 3-way terminal block, with its wire entry holes facing the outside of the board.

If you are going to fit LED1 onboard, do it now, with its longer anode lead

soldered to the pad marked 'A'. Otherwise, you could mount a header in its place, or solder a twin lead later.

Also install the two 10Ω 1W resistors now. Bend their leads so that they are suspended a few millimetres above the PCB surface to allow air to circulate, as they get pretty hot. As mentioned last month, you could opt to use 2W resistors, or perhaps four 4.7Ω 1W resistors arranged in pairs and mounted vertically to spread out the heat load.

Next, fit all the electrolytic capacitors, with their longer positive leads to the pads marked with a + symbol. Note that the two 47μF caps need to have their leads splayed out to fit the pads provided.

That just leaves the RCA sockets. The right-angle sockets will have plastic tabs that clip into the holes drilled into the PCB. Once you have pushed them down fully so they are flat on the PCB, solder their leads. You should also push the vertical connectors down fully before soldering the two tabs and central pin on each.

Building the Backpack

You have the option of using the *Micromite Backpack V2* with a 2.8-inch colour touchscreen (*PE*, May 2018)

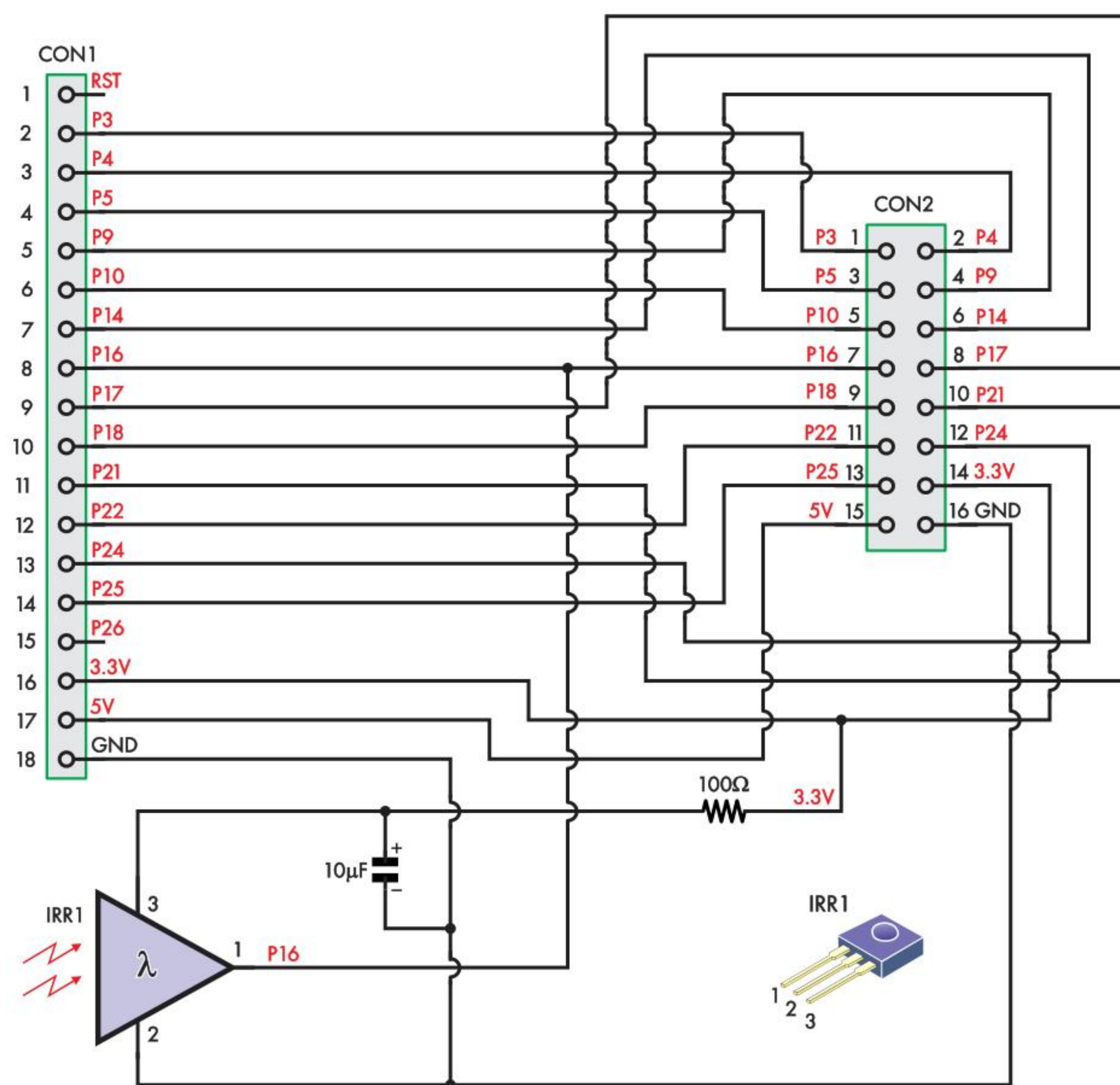
or the *Micromite Backpack V3* with a higher-resolution 3.5-inch touchscreen (*PE*, August 2020).

The main advantages of the 2.8-inch version are lower power consumption and the fact that it will more easily fit into a slimmer case. The 2.8-inch screen module is 38.5mm tall, while the 3.5-inch screen is 56.5mm tall. A 1RU case is 44.5mm tall, so it would be difficult to fit the 2.8-inch version into one, while fitting the 3.5-inch version would be impossible. A 2RU case would fit either.

Regardless, it's up to you; build the display version you prefer based on the instructions published in those previous issues. Assembly is pretty straightforward.

We can supply a PCB for either version – just go to the relevant month in the *PE PCB Service*. For all other Micromite/*BackPack* items we recommend using: micromite.org

Whichever version you purchase, make sure to select the right software. If you're programming the chip yourself (eg, you already have a *BackPack*), note that there are two versions of the software to suit the two different *BackPack* and screens. See the panel on loading the software below for details.



Micromite Preamp Interface Adaptor

Fig.8: this small adaptor circuit makes it easy to wire up the Preamp board to the Micromite LCD Backpack using a ribbon cable with standard IDC connectors crimped at each end. The IR receiver and its supply filter are only fitted to the board at the Backpack end.

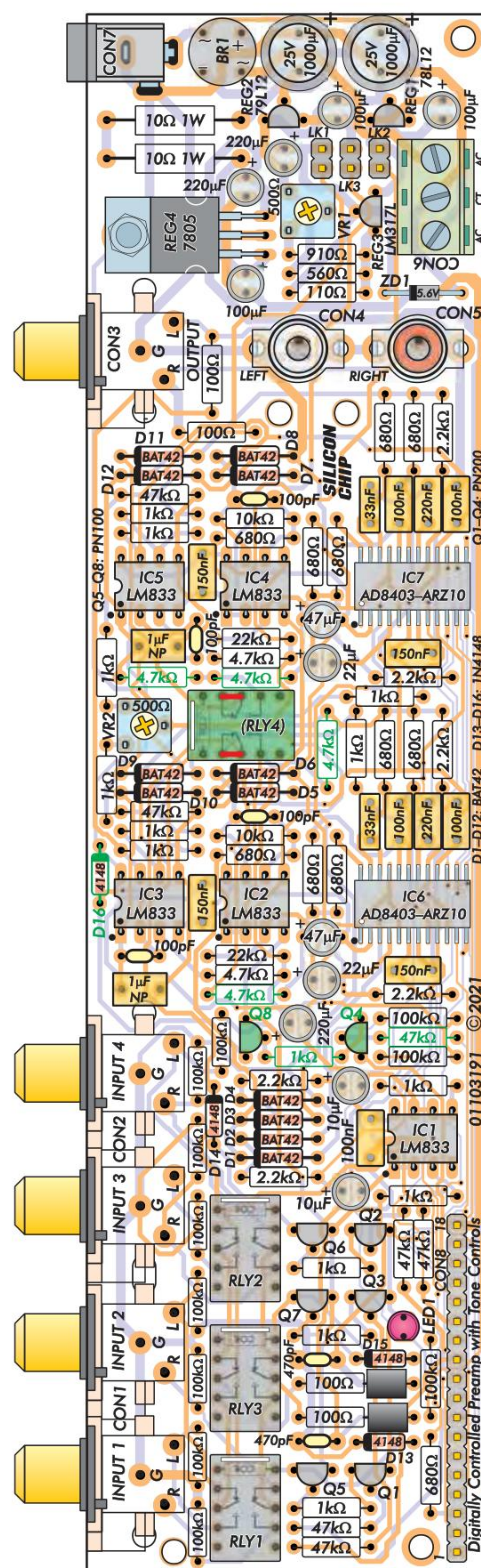


Fig.7: rather than fitting RLY4, we suggest you solder short wire links (shown in red) and then omit the other components (in green) including Q4, Q8 and six resistors. This is the tone control bypass circuitry which we found didn't improve the performance. Also, watch the orientation of the ICs, relays and diodes, especially IC6 and IC7, as they are hard to reverse if you get it wrong. They should have a dot or divot in the corner to indicate pin 1.

Wiring it up

Next, we need to make up the cable and adaptors that will connect the *Micromite BackPack* to the *Preamplifier* board. The one which attaches to the *BackPack* also hosts the infrared receiver (see Fig.8).

The two adaptors use identical PCBs (coded 01103192, measuring 12.5 x 45.5mm – available from the *PE PCB Service* (September 2022)). Both are fitted with a SIL header socket strip and a box header, but only one has the resistor, capacitor and infrared receiver onboard. This is the one that plugs into the *BackPack*. Assemble them as shown in the photos and the overlay diagram, Fig.9.

Next, you will need to crimp the IDC sockets onto the ribbon cable, as shown in Fig.10. Adjust the length of this cable to suit your installation. Ideally, you should use an IDC crimping tool to do this (for example, the Altronics Cat T1540). However, in a pinch, you can do it in a vice (pun intended) with pieces of timber on either side to protect the plastic.

Note that some IDC connectors come in three pieces, as shown in our diagram, with a bar on top to clamp the strain relief loop and another part below to press the cable down onto the blades in the socket. But we've also seen two-piece connectors with no strain-relief bar, and if you have that type, omit the loops.

Assembly needs to be done carefully, so note the following two points. First, don't compress the plastic so much that you break the top-most part of the connector – it's not hard to do.

Second, make sure that pressure is applied evenly, and all the parts of the socket have been fully pressed together (listen for clicks). This is so that the blades all cut through the insulation and make contact with the copper inside. The main cause of failures in these ribbon cables is due to one or more of the blades failing to cut through the insulation fully, leading to open-circuit connections.

For some installations, it might be better to crimp the IDC connectors onto opposite sides of the ribbon cable, rather than the same side, as shown in Fig.10. You can do it either way, as

long as you make sure that the triangle moulded into the IDC socket indicating pin 1 points to the red-striped wire in the ribbon cable at either end.

Testing

You can perform some basic tests on the main board before connecting the ribbon cable to it. Even if you plan to power the final device from a mains transformer, you can use a 12V AC plugpack or dual-tracking bench supply for testing.

With links LK1-LK3 open and nothing connected to the board, apply power. Use a voltmeter to probe the pins on the headers for LK1-LK3 closest to the edge of the board, taking care not to accidentally short across the pairs of pins. A convenient ground point for the black probe of the DVM is the mounting screw for REG4.

You should get a measurement close to +5.5V for LK1, +12V for LK2 and -12V for LK3. Adjust VR1 until the reading for LK1 is between 5.49V and 5.50V (or as close as you can get). If you can't achieve that, or either of the other two readings is way off, remove the power and check for faults in the power supply area.

Also check the +5V rail, which will power the *BackPack* by probing the right-most lead of REG4. It should be between 4.8V and 5.2V.

We'll assume that you have already loaded the software onto the *BackPack*; if not, unplug it and do so now, using the usual procedure. The panel titled *How to Load the Preamp Software* has some helpful hints.

If you can apply 5V power to the *BackPack* (eg, using a USB cable with JP1 fitted for the V2 or V3 *BackPacks*), then you can check that the software loads up normally. Press the buttons and step through the screens. Everything should 'work'; it just won't do anything without the *Preamplifier* board connected.

Assuming it all looks good, remove the power and wait a minute or so for the capacitors to discharge. Now place shorting blocks on LK1-LK3. Plug the ribbon cable firmly into the adaptor board without the IR receiver, then plug its SIL socket into CON8, oriented as shown in our photos.

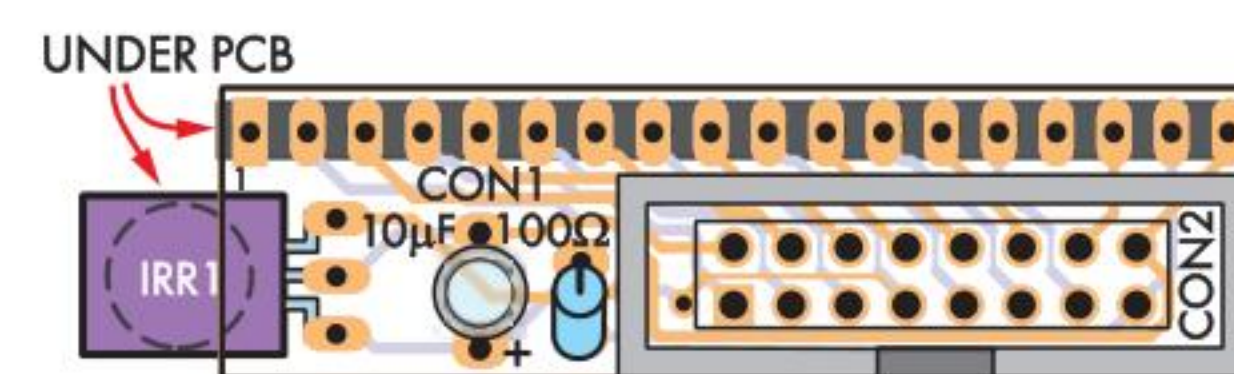


Fig.9: build one Adaptor board with all the components, as shown here (refer to our photos to see how we bent the IR receiver lead to reach the front panel), while the second Adaptor board should only have CON1 and CON2 fitted.



One of these Adaptor boards needs to be connected to the Micromite BackPack, as shown in the lead photo.

Similarly, plug the ribbon cable into the other adaptor board and the *BackPack's* I/O header, as in our photos.

Now is a good time to verify continuity between pin 1, where the header mounts on the *BackPack* PCB, and on the *Preamp* PCB, right in the corner. This will verify that you haven't reversed the connections anywhere. It's a good idea to check all the pins for continuity between the two boards, as this can show up ribbon cable crimping problems or soldering problems.

Once you're satisfied, reapply power to the *Preamp* board and verify that the LCD screen comes alive, and you can switch between Presets 1-4 by pressing the buttons. By default, these select between inputs 1-4, and you should hear soft clicks coming from the relay(s) each time you switch inputs.

Next, adjust VR2 to get exactly half the 5.5V rail voltage at pin 5 of IC4 (ie, very close to 2.75V if your 5.5V supply is spot on).

Now it's time to connect the *Preamp's* outputs to an amplifier with its volume wound down, and one of the stereo inputs to a signal source such as a Blu-ray or MP3 player. Select that input by pressing the associated preset button on the screen. This should pass the signal through more-or-less unaltered, although it might be somewhat attenuated.

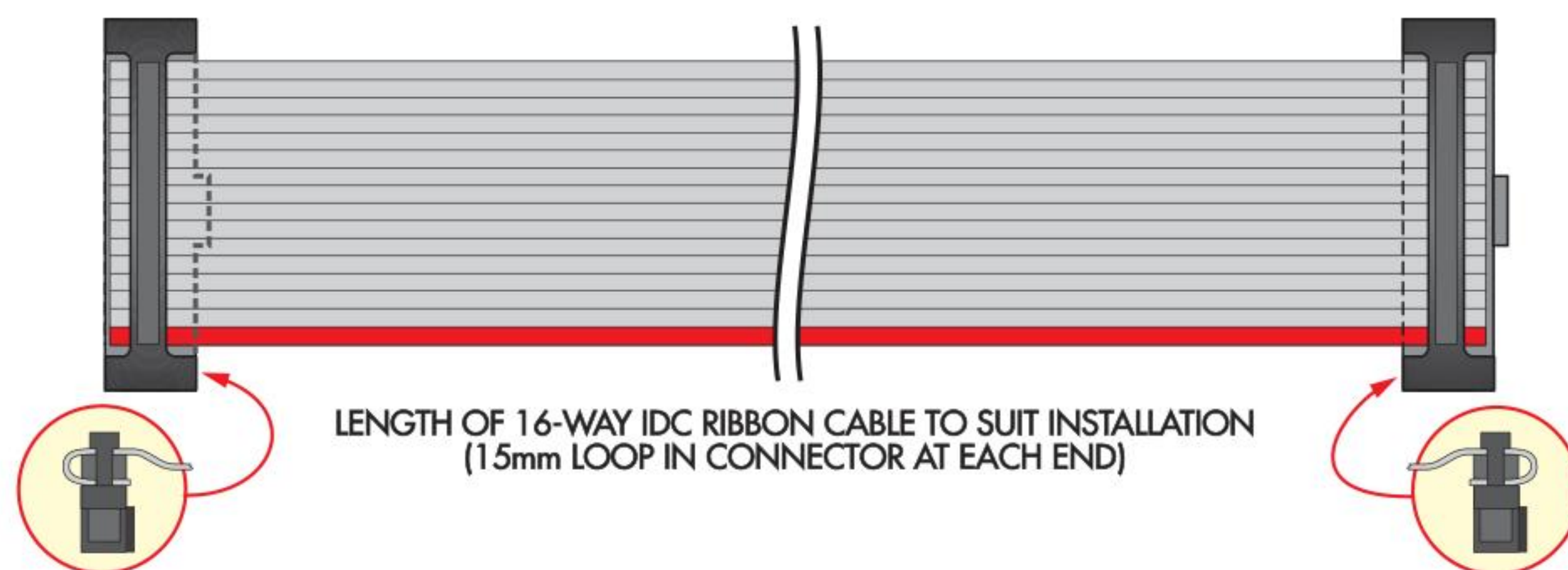


Fig.10: here is one way to assemble the ribbon cable. You can also put the IDC connectors on opposite sides of the cable if it suits your installation better; just make sure that the pin 1 triangle marking on each socket points to the red striped wire in the cable. Also be careful to crimp the connectors properly (firmly) without doing it so hard that you shatter the plastic.

Start the signal source and slowly wind the amplifier volume up to confirm that you can hear the audio passing through the *Preamp*. Ensure it is not overly distorted and that both channels

are present; otherwise, you probably have a circuit fault. If it seems OK, adjust the volume using the on-screen controls, and check that switching to another input effectively mutes the signal.

You can also now go into the EQ settings screen and try adding some bass/mid/treble boost or cut, to verify that those sections of both channels are operating correctly.

How to Load the Preamp Software

Loading the software

As you might expect with the option to run the software on either a 2.8-inch or 3.5-inch display, there are two different HEX files. The MMBasic software is written to work with both but requires different display drivers.

If you have a blank chip, use a PIC programmer or the onboard Microbridge to load the appropriate HEX file, as this is less effort than loading MMBasic and then loading the program separately. None of these choices exclude you from accessing and tweaking the MMBasic program to customise it.

The HEX file is named **0110319A Preamp 2.8in.hex** for the 2.8-inch display or **0110319B Preamp 3.5in.hex** for the 3.5-inch display.

Loading the software from scratch

If you are building the Preamp with the 2.8-inch display, you simply need to configure the Micromite to work with that screen. From the console, enter the following commands:

OPTION LCDPANEL ILI9341, LANDSCAPE, 2, 23, 6

and for the touch panel:

OPTION TOUCH 7, 15

Then calibrate the touch panel using the same parameters as we have in our HEX file:

GUI CALIBRATE 0, 143, 293, 893, 685

If the above calibration is not accurate, you can simply run:

GUI CALIBRATE

... to perform a full manual touch calibration.

Using the 3.5-inch display

Since the Micromite firmware does not include a driver for the ILI9488 touch controller in the 3.5-inch panel, a separate library file needs to be loaded to provide that feature and activate it when the Micromite starts up.

Load the **ILI9488 Library.bas** file onto the Micromite using MMEdit or your preferred serial terminal program. Enter the following commands at the Micromite prompt:

LIBRARY SAVE

CPU RESTART

OPTION TOUCH 7, 15

GUI CALIBRATE 0, 3891, 3851, -1277, -860

Again, you can simply use the GUI CALIBRATE command without parameters if you find our calibration doesn't match your hardware.

At this stage, you will have a Micromite loaded with an appropriate display driver, which you can test with the GUI TEST LCDPANEL and the GUI TEST TOUCH commands.

The MMBasic file

The MMBasic file is designed to work with either display driver; indeed, any display with a similar or higher resolution to the 2.8-inch display should work, although we can't vouch for the scaling on other screens that we haven't tested.

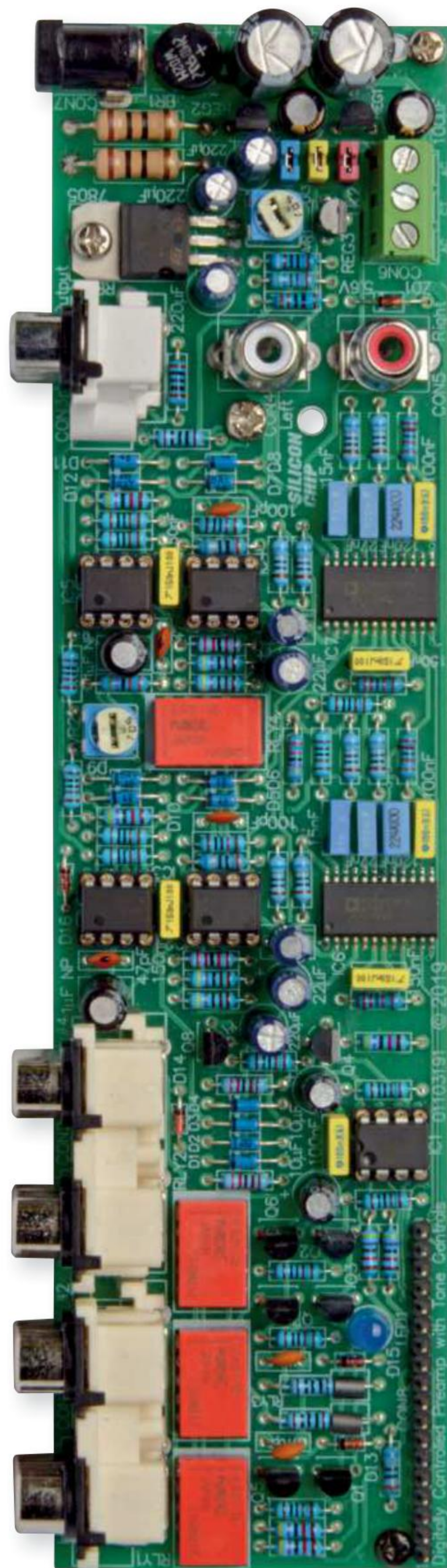
This file also contains an abridged version of the above notes in comments near the start of the file.

Simply load the **Digital Preamp.bas** file using MMEdit or your serial terminal program and run it from the MMBasic prompt. You should be greeted by the MAIN screen and the sound of relays clicking as the Digital Preamp initialises.

The initial condition has input one connected with nominal midpoint (all zeroes) volume, preamplifier and tone control settings. This corresponds to modest gain across all bands. At this stage, the Micromite is in the same state as if it were loaded with the HEX file as described earlier.

Remote control

Now is also a good time to test out the remote control, if you plan to use one. The Jaycar XC3718 should 'just work' while the Altronics A1012A needs to be set to Aux preset 0776 (see its manual for details on how to do that).



The updated Altronics A1012A Universal Remote

Altronics has recently updated their A1012 Universal remote control to a newer model, the A1012A (www.altronics.com.au). We have used the A1012 to control our projects for many years now (along with some contemporary Jaycar remotes). This new model has some minor changes compared to the earlier version, which affect how it works with the Digital Preamp.

While the design, styling, and button layout have changed, many button functions are the same. The six device buttons near the top have changed too, with the CD and VCR buttons being replaced by DVD and HD buttons.

The setup process for the A1012A is similar to the older A1012. You select one of the devices using its button near the top, press the SET button, then enter a code. The A1012A uses four-digit codes, while the A1012 used three-digit codes. A glance through the codes list for both devices shows at least a partial correspondence between the two units.

For example, we often use AUX code 171 for Micromite projects. The testing we did a few years ago showed that this setting produces distinct codes that are consistently detected by MMBasic's inbuilt IR decoder.

In the A1012 code list, this code is shown as third in the list for several manufacturers. When we referred to the A1012A's code list and tried the third code for the same manufacturers, we found that it gave the same codes and thus worked with our Digital Preamp.

So AUX code 0776 on the A1012A is a good substitute for AUX code 171 on the A1012. We haven't exhaustively tested all the buttons, but it certainly worked for all the functions we tried.

Over the last few years, we've created a few projects that use A1012 TV codes 089 and 170. It appears that TV codes for the A1012A don't correspond one-to-one to those of the A1012, presumably due to newer TVs evolving and having more features.

Still, we found that the codes 0088, 0149 and 0169 were suggested for TVs on the A1012A's code list that would have required TV codes 089 and 170 on the A1012.

So we tested these codes with an Arduino board that we had equipped with an infrared receiver (see: **Control your PC with an infrared remote**, PE, August 2019 for the hardware we used). The codes that we received were all identical to those used for the A1012, so it appears that these remotes are mostly interchangeable, and probably only differ in the more obscure codes.

Thus, if you are updating any Micromite projects from the A1012 to the A1012A, we suggest using AUX code 0776.

Other projects we have published that make use of the A1012 include:

- **Currawong Valve Amplifier**, PE, November 2015 to January 2016
- **High Visibility GPS Clock**, PE, January-February 2017
- **Preamp and Input Selector**, PE, April-June 2020
- **Altronics MegaBox**, PE, January 2019.

All of these use the TV codes mentioned above, so they should work fine with the A1012A programmed with TV codes 0088, 0149 or 0169.

Note that the Jaycar Cat AR1975 'Total Control 4 Device TV Remote Control' is similar to the Altronics A1012A in many ways, and we will likely use that in future projects where their small XC3718 remote cannot be used (eg, due to having just 21 buttons, which was enough for this Preamp).

Remote control code map:

A1012	A1012A
AUX 171	AUX 0776
TV 089 or TV170	TV 0088, TV 0149 or TV 0169



Screen 9: we showed photos of most of the screen displays last month, but here's one we didn't show: the large volume number shown when you adjust the volume via the remote control. It's large enough to see across a room. Each step equates to about one-third of a decibel.



In this screen, you can adjust the tone control and preamplification settings and see how the Preamp's frequency response will be affected.

buttons 7 (bass), 8 (mid-range) or 9 (treble)

- Number keys 1-6 should select one of the six presets

Final wiring

After mounting the unit in the case, all that's left is to wire up the power supply – assuming you aren't using the onboard barrel socket.

If you have a transformer with a single secondary, wire it between either pins 1 and 2, or 2 and 3 of CON6. If it has twin secondaries, connect them in series in-phase and then wire the junction to pin 2 of CON6 and the other ends to pins 1 and 3, either way around. Similarly, if it's a centre-tapped secondary, connect the tap to pin 2 and the other wires to pins 1 and 3.

If you have a source of $\pm 15V$ DC, wire the rails to pins 1 and 3 of CON6 either way around, with GND to pin 2.

If you are building the *Preamp* into a full amplifier, connect RCA plug leads to the amp module inputs and plug them into the vertical outputs (CON4 and CON5) on the board. You should be ready to rock'n'roll – or whatever takes your fancy!

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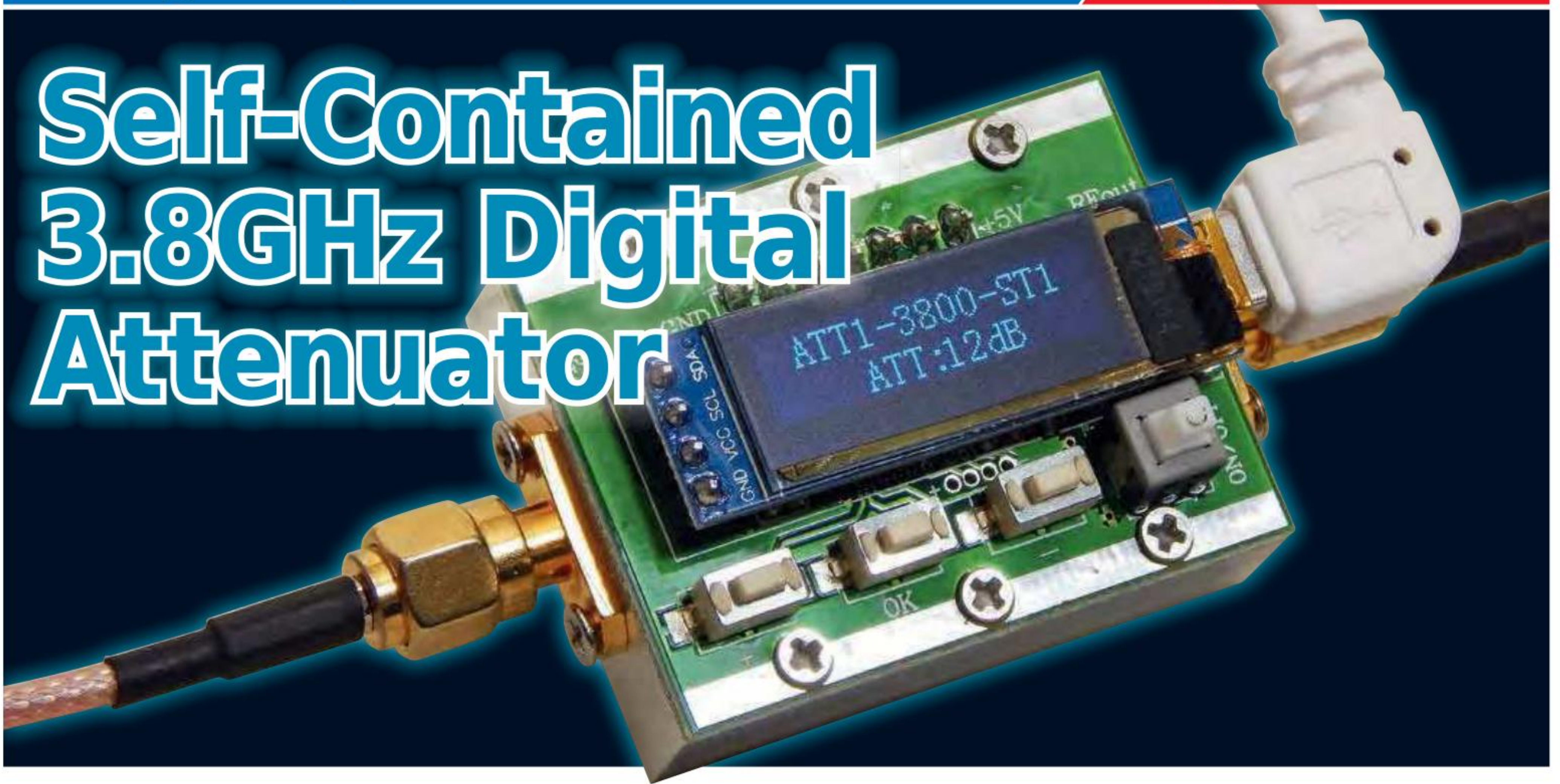


Point the remote at the IR receiver and check the following functions:

- Volume up/down should change the audio level, and you should get a large on-screen display to show you the new volume level (see Screen 9); the popup only shows on the MAIN screen

- The mute button should toggle the mute function; since the Jaycar remote lacks a mute button, the play/pause button operates this function
- The CH UP and CH DN keys can be used to tweak the band settings after first selecting a band using

Self-Contained 3.8GHz Digital Attenuator



This digitally programmable RF attenuator module can attenuate RF signals from 1MHz to 3.8GHz by 0–31dB in 1dB steps. It doesn't need to be controlled by an external microcontroller; it has one built in. You control it using four small pushbutton switches, while a tiny OLED screen shows the current setting.

I reviewed one of the simpler digitally programmable RF attenuator modules back in the June 2019 issue of *PE*. It could be configured either by a separate microcontroller unit (MCU) like a Micromite or Arduino, or a six-way DIP switch.

It was based on the Peregrine Semiconductor PE4302 attenuator IC, mounted in the centre of a 33 x 24.5mm PCB without any shielding. Despite that, it turned out to have quite respectable performance up to about 1.5GHz. Above that, attenuation errors tended to grow, but the module was still quite practical for many applications.

I recently noticed a new digitally programmed step attenuator for sale. It is only a little larger, but has a built-in MCU with a tiny OLED and some small pushbutton switches for easy attenuation adjustment. I ordered one from Banggood (ID number 1769385; also available from AliExpress – search for: 'HMC472 6-bit Digital Attenuator').

At the time of writing, it is priced at about £14 plus £3 for shipping to the UK. I haven't been able to find any information regarding its manufacturer, but like most of these modules, it is almost certainly made in China.

This module measures 42 x 32 x 22mm overall, not counting the SMA connectors at each end for RF input and

output. The digital attenuator section is on a 33 x 22.5mm PCB inside a 42 x 32 x 10mm CNC machined aluminium block which forms the 'case'.

Most of the control section is mounted on a second PCB measuring 42 x 32mm, which forms the top of the case. The 26mm diagonal (38 x 12.5mm) OLED is mounted on top of the second PCB.

The PE4302 digital attenuator chip used in the earlier attenuator module was made obsolete in 2018 and is no longer available. This new module uses the HMC472 from Hittite Microwave Corporation, a company acquired by Analog Devices in 2014.

The HMC472 is similar to the PE4302 in many ways. It is described as a 6-bit digital step attenuator using GaAs MMIC technology, and can provide attenuation from 0dB to 31.5dB in 0.5dB steps for DC to 3.8GHz signals. It comes in a 24-lead Lead Frame SMD package measuring 4 x 4mm. Unlike the PE4302, it runs from 5V DC rather than 3.3V.

The insertion loss at the 0dB setting is rated at 1.1–1.2dB below 350MHz, 1.5dB at 2GHz and 1.9dB at 4GHz.

I wasn't able to find a complete circuit for the new module, but I worked out a basic block diagram for it, shown in Fig.1. The HMC472's RF1 input pin

is coupled to the SMA connector via a 1nF capacitor, with its RF2 output pin configured similarly. Apart from various bypass capacitors, that is the whole attenuator section.

The control section is based on an STM32F103C8T6 microcontroller. You may have noticed that it controls only five of the six programming lines of the HMC472: V1 to V5. The unused V6 line is the one that controls the 0.5dB attenuator stage inside the HMC472, which explains why this module only provides 1dB steps.

Presumably, the module designers decided that given the attenuation error rating of the HMC472, $\pm(0.35\text{dB} + 5\%)$, and the difficulty in avoiding further frequency-related errors due to, for example, PCB layout, there wasn't much point in providing 0.5dB steps.

The user determines the attenuation setting using the three small pushbutton switches (S1–S3), and the current attenuation setting is shown on the OLED module. The MCU drives this via a standard I²C serial interface.

When power is first applied, the MCU sets the attenuation to 0dB. To increase the attenuation, you first press S2 (the OK button) and then press S1 (+) until the display shows the attenuation setting you want. Then, if you press S2 again, this will be the new setting. To

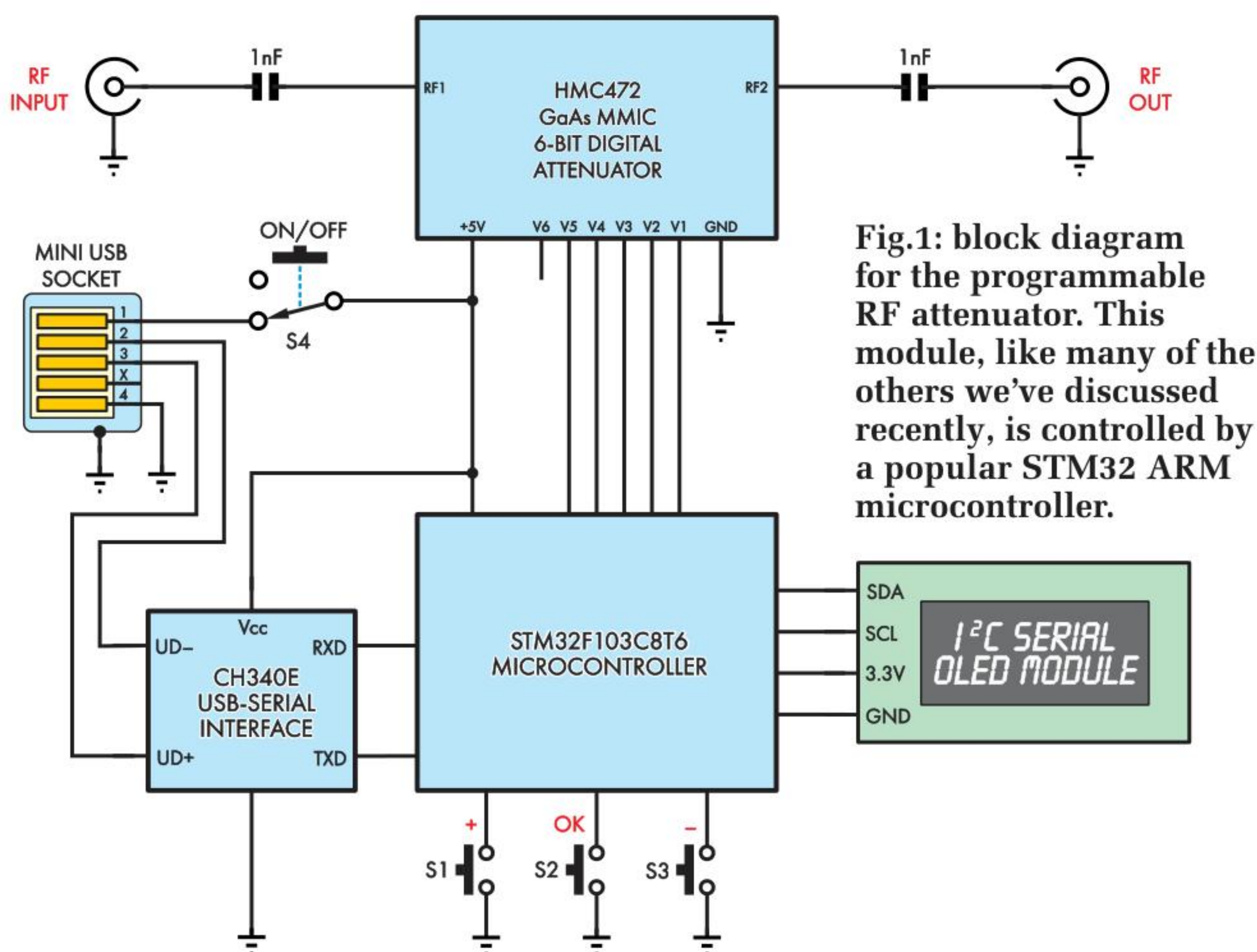


Fig.1: block diagram for the programmable RF attenuator. This module, like many of the others we've discussed recently, is controlled by a popular STM32 ARM microcontroller.

reduce the attenuation, you press S2 once more, then press S3 (–) until the OLED shows the new setting you want, and then press S2 again.

It's pretty straightforward, although the tiny pushbuttons used for S1-S3 do have a small amount of contact bounce. This can sometimes force you to press the + or – button again to correct any accidental 'overshoot' before pressing S2 to finalise the change.

The CH340E USB-serial interface chip shown in Fig.1 has been provided to allow the attenuation setting to be programmed from a computer. So the mini USB socket is not just for feeding power to the module (controlled by power switch S4), but also to allow external control.

There's not a great deal of information provided on external control, but

I found a very brief explanation in the 'Customer Q&As' section of the Banggood info on the module:

The protocol is simple 9600 Baud serial: 'wvXXYYn' sets the attenuator to XX.YYdB. 'rn' returns the model number. Search GitHub using ATT6000 or emptemp for python code (https://github.com/emptemp/att6000_control).

I tried this, but I didn't get very far. Using the serial terminal app Tera Term (V4.105) with the virtual com port driver set for 9600 baud, I tried all of the possibilities I could think of to try and get the attenuator module to 'listen' to a command like 'wv1300n'.

I tried sending the command in uppercase instead of lowercase, with and without the 'n' at the end, followed by an LF or a CR or a CR-LF, using 8-bit coding or 7-bit coding and so on. But there was no response or reaction from the module, whatever I tried. It stayed stubbornly set at 0dB of attenuation.

So I'm not sure about how to control the module from a PC or MCU.

Checking it out

I measured the performance of the new attenuator module using my Signal Hound USB-SA44B HF-UHF spectrum analyser and its matching USB-TG44A tracking generator, both controlled by the latest version of Signal Hound's Spike

software (V3.5.15) in its SNA (scalar network analysis) mode.

I checked the performance of the module at a number of different attenuation settings: 0dB (to see its insertion loss), –5dB, –10dB, –15dB, –20dB, –25dB and –30dB, to get an idea of the module's overall performance. After examining the results I then checked the response at three further settings: –1dB, –18dB and –31dB.

During each of these tests, I saved an image of Spike's plot of the test results. The first of these (the one for a setting of 0dB) is shown in Fig.2.

Spike cannot combine multiple results into a single composite plot, so I assembled one by importing them into CorelDraw and tracing each plot. The result is shown in Fig.3.

The uppermost 0dB plot shows the insertion loss of the module over the entire frequency range. It is less than 2dB (as claimed) up to about 1.5GHz, but then wobbles around a bit until it reaches about –2.5dB at 2.64GHz and then –3.5dB at around 2.95GHz. Essentially, the insertion loss remains under 2.0dB over much of the frequency range, apart from some deviations between 1.5GHz and 3.8GHz.

Most of the lower plots in Fig.3 have a shape almost identical to that of the top 0dB plot, just separated by the chosen attenuation setting. This is also true for the uppermost blue line, with the attenuator set at –1dB.

But notice that above about 2.2GHz, the higher attenuation plots (–20dB and greater) develop a small number of minor bumps and dips. These are very apparent in the –30dB plot, for example, and also in the blue –31dB plot just below it. I suspect that many of these minor variations are due to small resonances inside the HMC472 chip and its surrounding tracks on the attenuator PCB. There might also be standing waves inside the attenuator box at specific frequencies.

These plots reveal that the attenuator's performance relative to its insertion loss is quite respectable, at least for frequencies up to about 1.5GHz and settings up to around –20dB. But the errors increase above 1.5GHz and with levels above –20dB.

This attenuator would still have many practical uses above 1.5GHz and settings over –20dB, either if the exact amount of attenuation at a given frequency is not critical, or if you use the plots of Fig.3 to correct for the errors.

The middle blue plot in Fig.3, for a setting of –18dB, was to see if setting the attenuator to –18dB would give an actual attenuation of –20dB over as much of the frequency range as possible. This worked for frequencies around

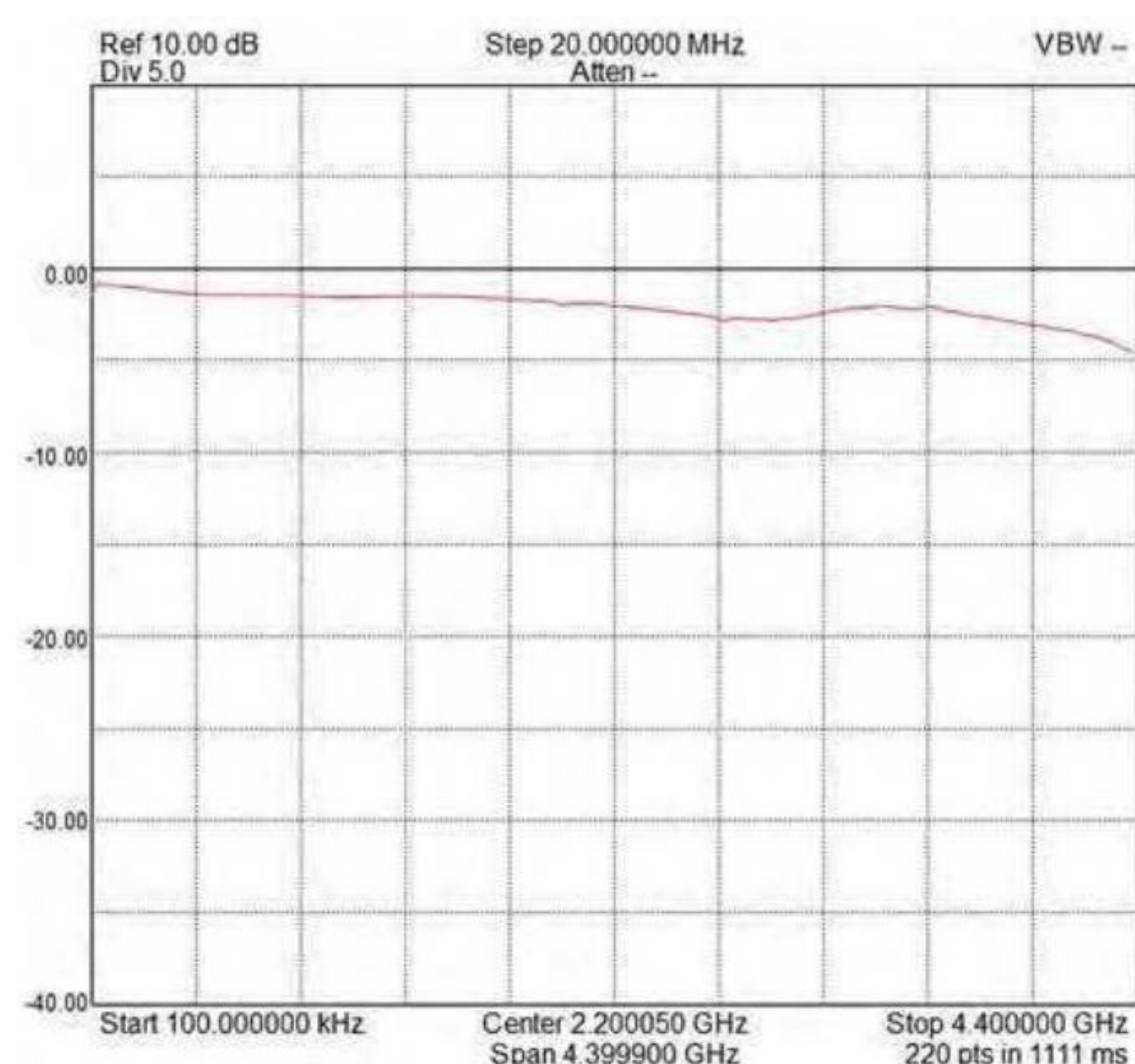
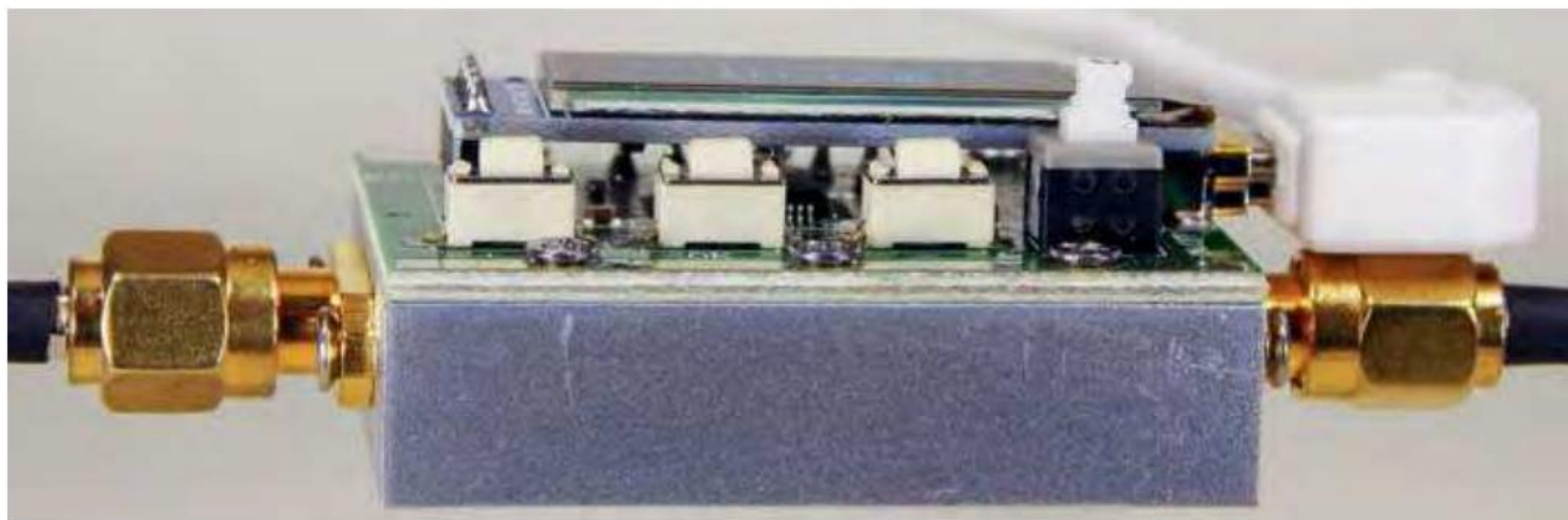


Fig.2: a graph of the module's performance at an attenuation setting of 0dB. This was measured between 100kHz and 4.4GHz, using Signal Hound's Spike software with a USB-SA44B spectrum analyser and a matching USB-TG44A tracking generator.



The side view of the attenuator module shows the control switches, and the very tight spacing between the RF and USB power connectors on the right. This photo is shown at approximately 150% scale for clarity.

880MHz and 3.8GHz, but the overall shape of the plot was unchanged and still gave significant deviations both less than and greater than the desired -20dB figure.

Conclusions

Overall, this new attenuator module is reasonably good value for money. It is suitable for a fairly wide range of applications, especially if you use the curves of Fig.3 to correct for the inevitable attenuation errors.

But it does have a few shortcomings. For example, the module might not be controllable from a PC, Arduino or Micromite.

Another is that the RF output SMA connector and the mini USB power connector are too close together, so you have to unplug the USB cable to connect or disconnect an SMA cable to the RF output just below it.

You also have to adjust the SMA connector's outer hex sleeve so that a flat is uppermost; otherwise, you won't be able to reconnect the USB cable.

Before I finished writing this review, I went onto the Banggood website to

check on the price of this module. I was surprised to see that a larger and apparently better module had become available (ID 1648810; <https://bit.ly/pe-oct22-att>).

This newer attenuator module is advertised as having a frequency range of LF to 6GHz, an attenuation range of 0-31.75dB in steps of 0.25dB and an insertion loss of less than 1.5dB (but with the qualification that 'it will be a little larger' at the high-frequency end).

Currently, they are advertising it for around £25, plus postage to the UK. So it costs nearly double that of the module I've reviewed here, but it might turn out to be worth it.

I suspect it is based on the Analog Devices HMC1119, which has a range of 100MHz to 6.0GHz, seven control bits to give a setting range from 0 to 31.75dB in 0.25dB steps and a specified insertion loss of 1.3dB at 2.0GHz. I am planning to order one of these and write it up when it arrives.

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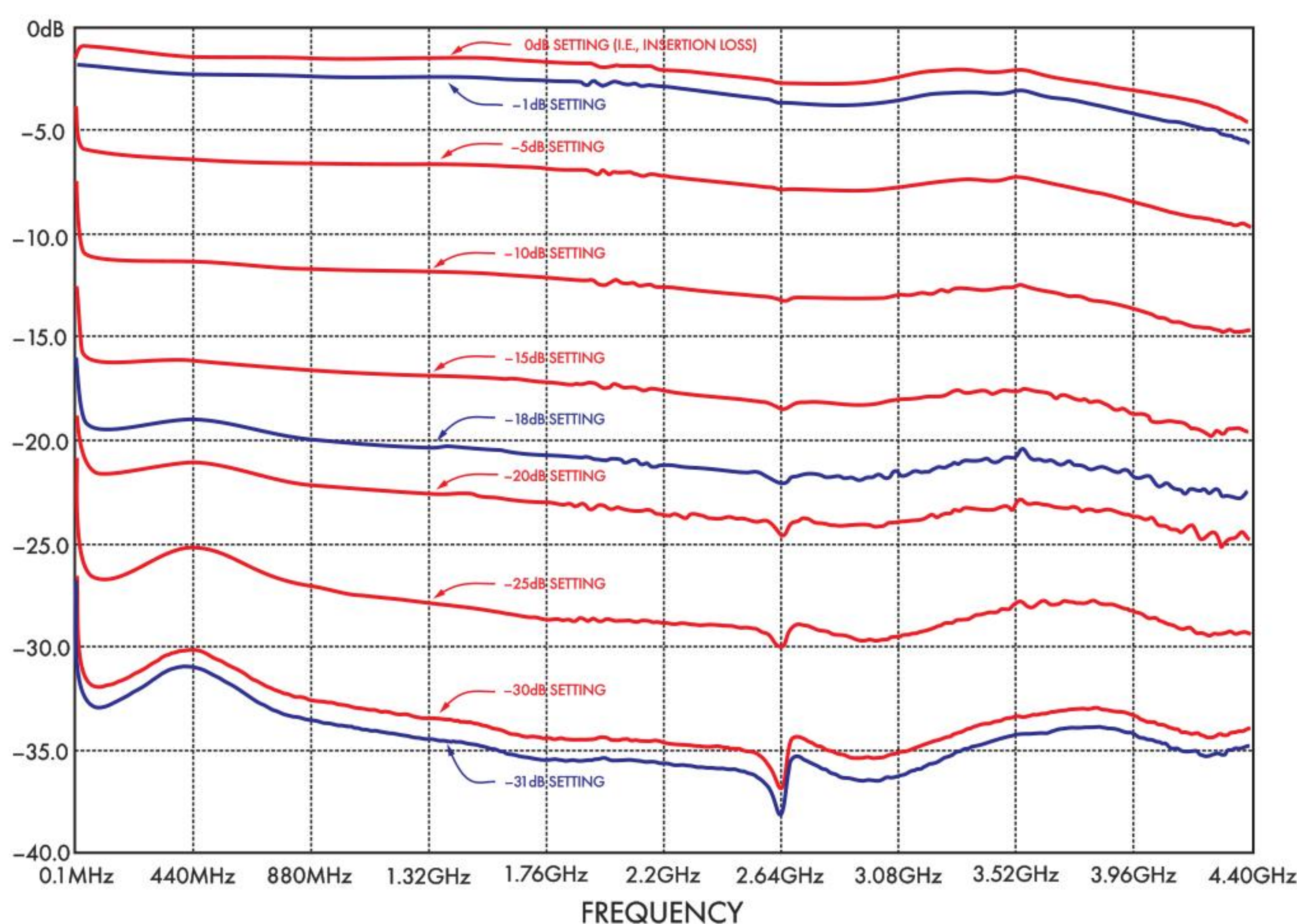


Fig.3: following on from Fig.2, this is the combined plot of testing the module at various attenuation settings from 0dB to -30dB in 5dB steps, and then three extra tests at -1dB, -18dB and -31dB.

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Circuit Surgery

Regular clinic by Ian Bell

Electronically controlled resistance – Part 2

Last month, in Part 1, we started looking at electronically controlled resistance. This was prompted by a question from user Kintaro posted to the EEWeb forum. Two key approaches to electronically controlled resistance are a) to use transistors, particularly JFETs (Junction Field Effect Transistors), as voltage-controlled resistors, and b) digital potentiometer ICs, which are typically controlled via a microcontroller over a standard bus such as SPI or I²C. Part 1 discussed some specific points raised by Kintaro, and we considered the properties of the JFET in relation to its use as a voltage-controlled resistor. This month, in Part 2, we will look in more detail at circuits using this technique – specifically use of the JFET attenuator, which employs a JFET as part of a potential divider circuit.

In Part 1, we explained how to use LTspice to plot the characteristics of a JFET, as shown in Fig.1. Similar plots are often provided on device datasheets. Fig.1 shows that we can divide the JFET's characteristics into two regions – saturation and ohmic. In the saturation region the JFET acts like a constant-current source between source and drain, with the current controlled by the gate-source voltage. This is employed when the JFET is used as an amplifier.

The JFET's ohmic region is characterised by resistive behaviour – increasing drain-source voltage (V_{DS}) results in an increase in drain current (I_D). The exact drain voltage-to-current relationship depends on the gate-source voltage. The slope of the curves on Fig.1 are inversely proportional to resistance, with the slope decreasing (higher resistance) with increasing magnitude of gate-source voltage (V_{GS}). Unlike an ideal resistor, the drain-source resistance (r_{DS}) is not perfectly linear, however, if we look at relatively small drain-source voltages (within the arc drawn near the origin) the lines are relatively straight – it is this part of the characteristic that can be used to implement a good voltage-controlled resistor.

As discussed last month, and shown in Fig.2, we can use LTspice to directly plot the drain-source resistance variation with drain-source voltage at various gate-source voltages. This shows the JFET's resistance varies from about 130 Ω to 390 Ω as V_{GS} is goes from 0V to -2V (at $V_{DS} = 0$ V). The plots in Fig.1 and Fig.2 are for an n-channel JFET, which requires a negative gate-source (resistance control) voltage. p-channel devices can also be used and require a positive gate-source voltage.

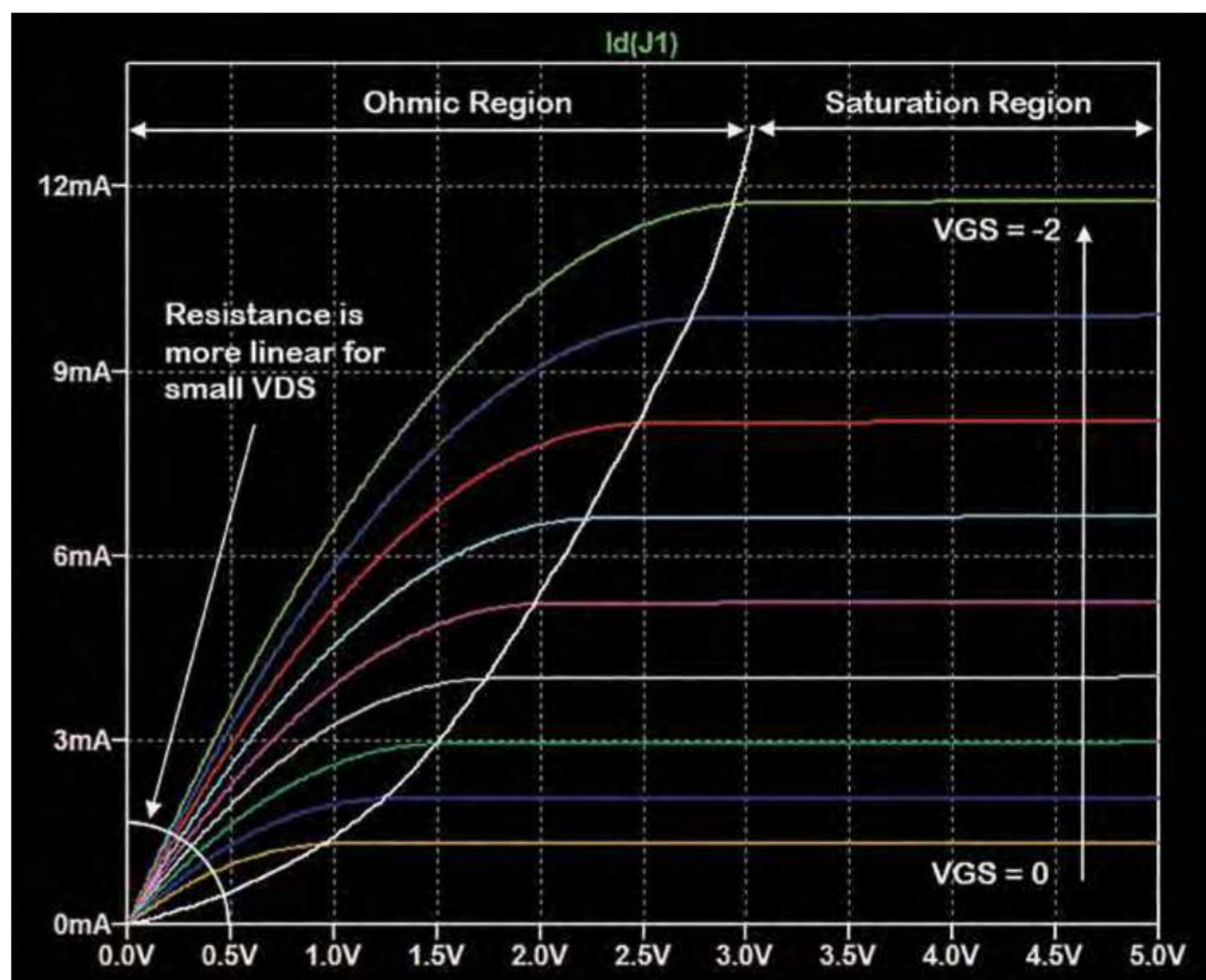


Fig.1. LTspice plot showing regions of operation in JFET characteristics (I_D vs V_{DS} at various V_{GS}). See previous month for simulation details.

Implications of device characteristics

Fig.2 shows the resistance is fairly constant over the plotted drain-source voltage range of ± 600 mV and is better for lower magnitudes of gate-source voltage. For both n and p-types, drain-source voltage can be of either polarity (Fig.2 covers both positive

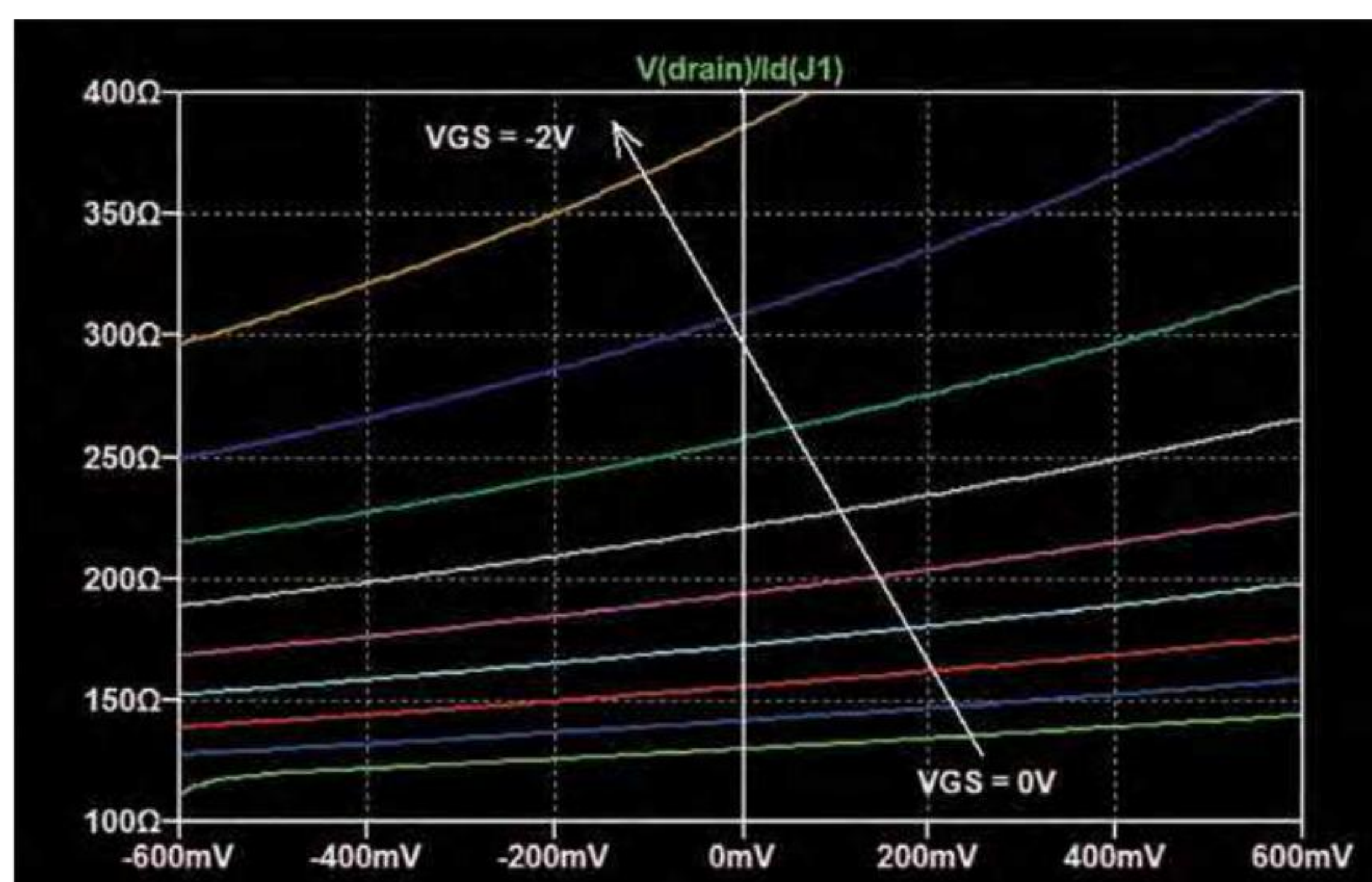


Fig.2. JFET drain-source resistance for various gate-source voltages for drain-source voltages around zero (± 600 mV) – see also Fig.1.

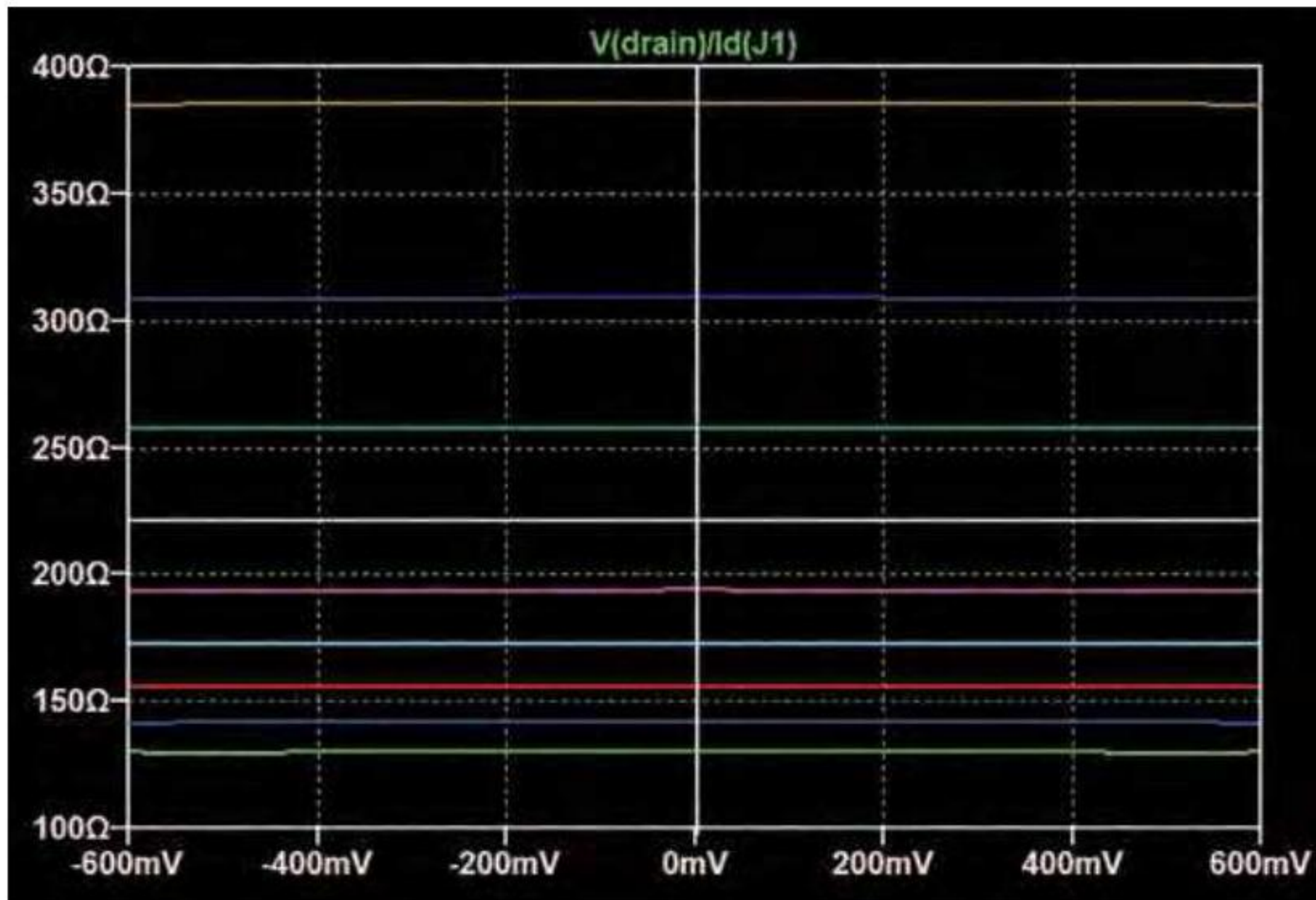


Fig.3. JFET drain-source resistance for various gate-source voltages for drain-source voltages around zero with feedback applied (compare with Fig.2).

and negative V_{DS}), which means we can have a zero-offset AC signal across the voltage-controlled resistor. The JFET resistor can operate with the ‘resistor’ voltage (V_{DS}) down to zero – it does not have a ‘turn-on’ voltage, or minimum V_{DS} for operation.

The plot in Fig.2 is for a 2N3819 JFET – the values for other devices will be different but follow a similar pattern. The 2N3819 was not specially selected – it was the first in LTspice’s list at the time of writing. The resistance range for different JFETs may be significantly different (eg, up to several kilohms, rather than the hundreds of ohms seen in Fig.2). A key device parameter is $r_{DS(on)}$, which is the minimum drain-source resistance (at $V_{GS} = 0V$) and depends on the physical structure of the device. A Vishay Siliconix datasheet for the 2N3819 states a typical $r_{DS(on)}$ of 150Ω at a 1mA drain current (implies V_{DS} is 150mV), which is close to what we see in Fig.2. However, not all the various 2N3819 datasheets quote this value directly. Using different JFETs from those specified in a voltage-controlled resistance circuit, implies potentially different $r_{DS(on)}$ values, which means that other component values may need to be changed.

As mentioned last month, the fact that drain-source resistance is non-linear (varies with drain-source voltage) means that circuits using JFET voltage-controlled resistors will introduce signal distortion. A key implication of this is that when we use the JFET as a voltage-controlled resistor, the signal voltage across it must be small – in the range of tens to low hundreds of millivolts. This means signals may need to be attenuated and amplified after being controlled by the JFET. Smaller signal voltages across the JFET reduce distortion, but also risk decreasing (ie, worsening) the signal-to-noise ratio. As we showed last month, the resistance non-linearity can

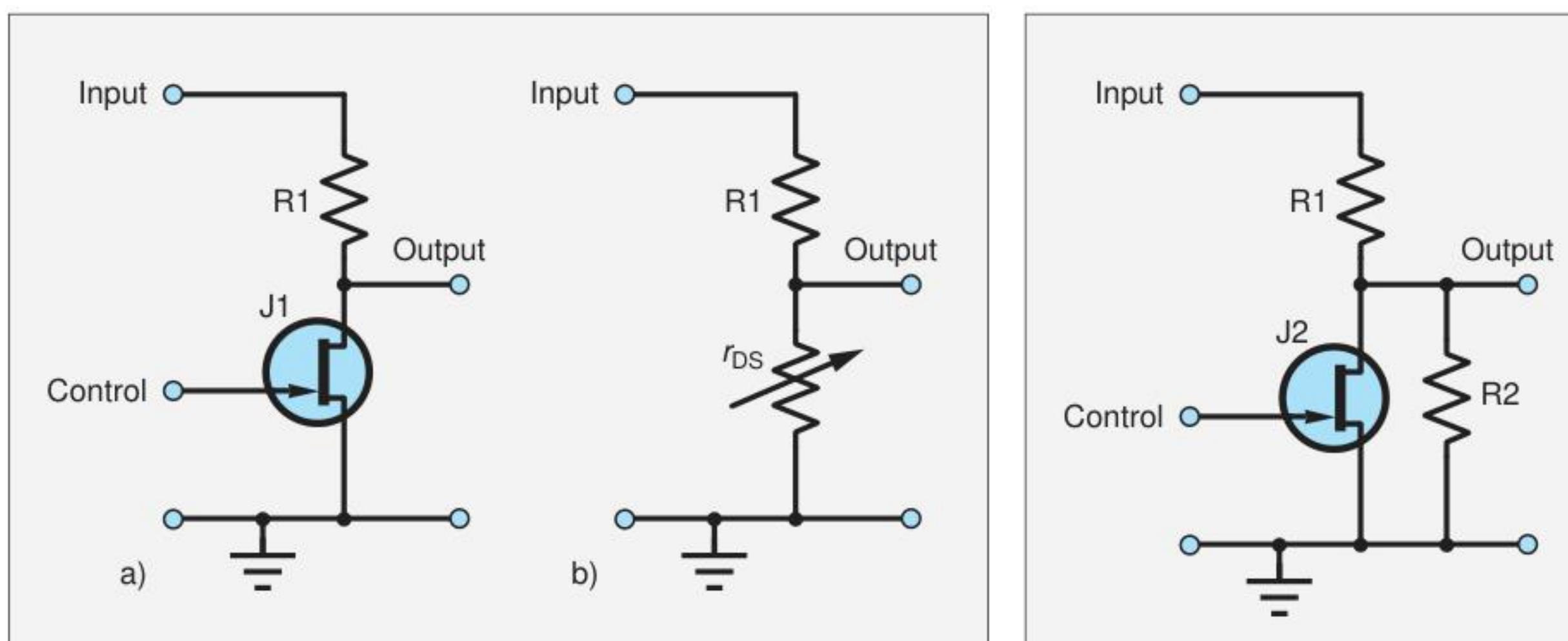


Fig.4. (left) (a) Basic JFET attenuator (b) Potential divider equivalent circuit. Fig.5. (right) JFET attenuator with series resistor.

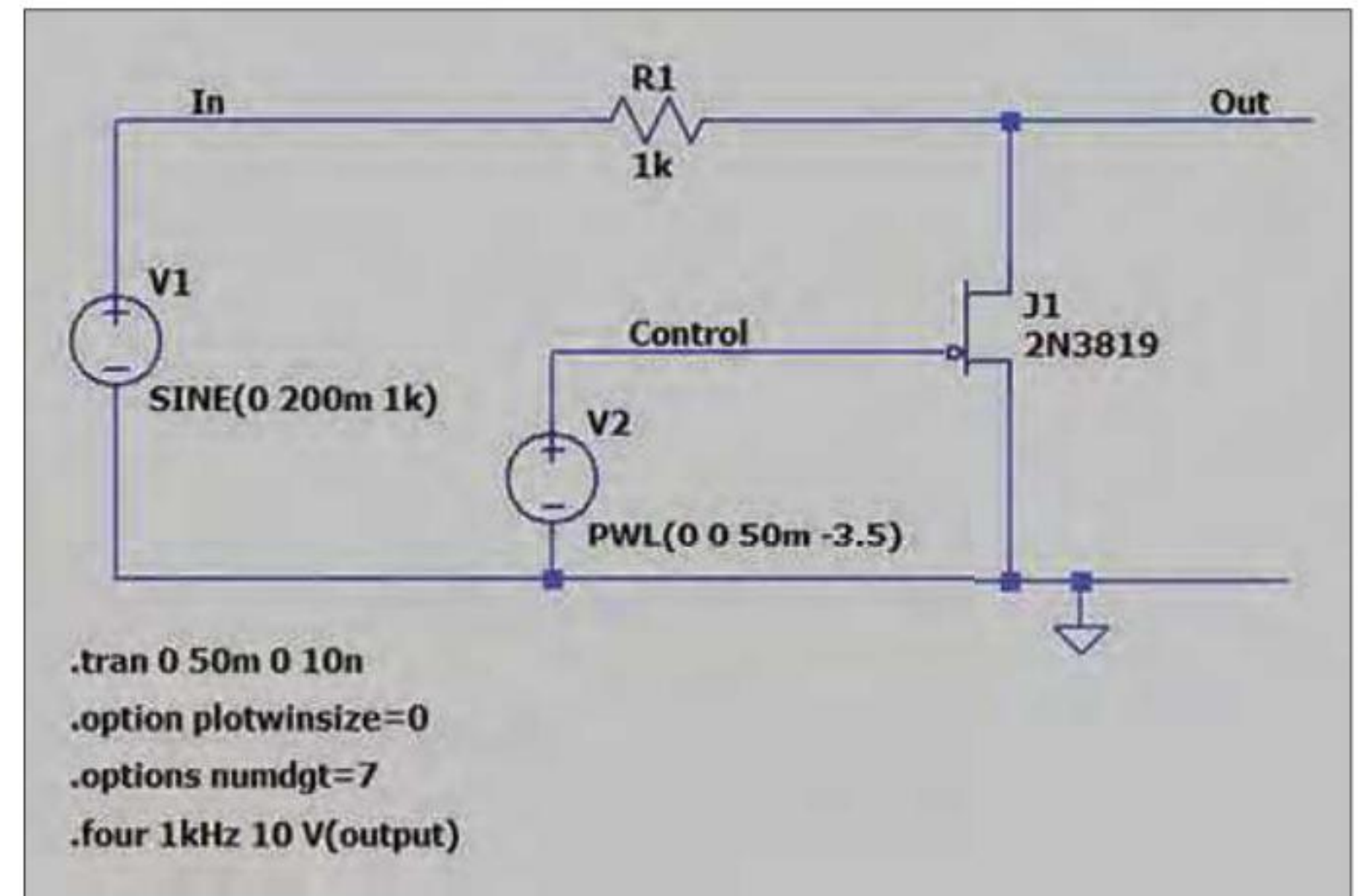


Fig.6. LTspice schematic for a basic JFET attenuator

be reduced by feedback (see Fig.3), and we will look at this again later.

Fig.3 shows the JFET’s resistance for a set of evenly stepped gate-source voltages (0 to $-2V$ in $0.25V$ steps). It can be seen that the curves for each V_{GS} value are not evenly spaced. This shows that the control-voltage-to-resistance relationship is also not linear. Variations in the gate-source-voltage-to-resistance relationship are likely to occur between individual devices of the same type, so in some circuits the ability to make adjustments (eg, using a trimmer potentiometer) may be required.

Voltage-controlled attenuator

The most basic use of a JFET voltage-controlled resistor is as a voltage-controlled attenuator in which the JFET forms

$$v_{out} = \left(\frac{r_{DS}}{R_1 + r_{DS}} \right) v_{in}$$

part of a potential divider. The simplest form of this circuit is shown in Fig.4. The output voltage is given by:

The output voltage can range from its lowest value when $r_{DS} = r_{DS(on)}$ (at $V_{GS} = 0V$), to very close to v_{in} if the JFET is switched off by applying a large gate-source voltage. The maximum output can be limited to less than v_{in} by adding a resistor (R_2) in parallel with the JFET, as shown in Fig.5. The output voltage can be found by substituting the parallel combination of R_2 and r_{DS} for r_{DS} in the equation above. We briefly discussed parallel combinations of voltage-controlled and fixed resistors last month.

If R_2 in Fig.5 is very large compared with R_1 then the maximum output will still be effectively equal to v_{in} , but the output will not be an open circuit if the JFET is off (with the input disconnected or very high impedance). This may be needed in some applications if an open circuit is not a desirable condition for whatever is connected to the output of the attenuator.

Attenuator simulation

Fig.6 shows an LTspice schematic for investigating the basic JFET attenuator. The input signal is a 1kHz sinewave, and the control voltage is ramped from 0V to $-3.5V$ over 50ms using a PWL (piecewise linear) source. The following SPICE directives:

```
.option plotwinsize=0
.options numdgt=7
.four 1kHz 10 V(out)
```

together with the 10ns minimum time step in the transient simulation command are included to facilitate distortion analysis. Performing FFT (fast Fourier transform) and distortion analysis in LTspice was discussed in the July 2022 issue,

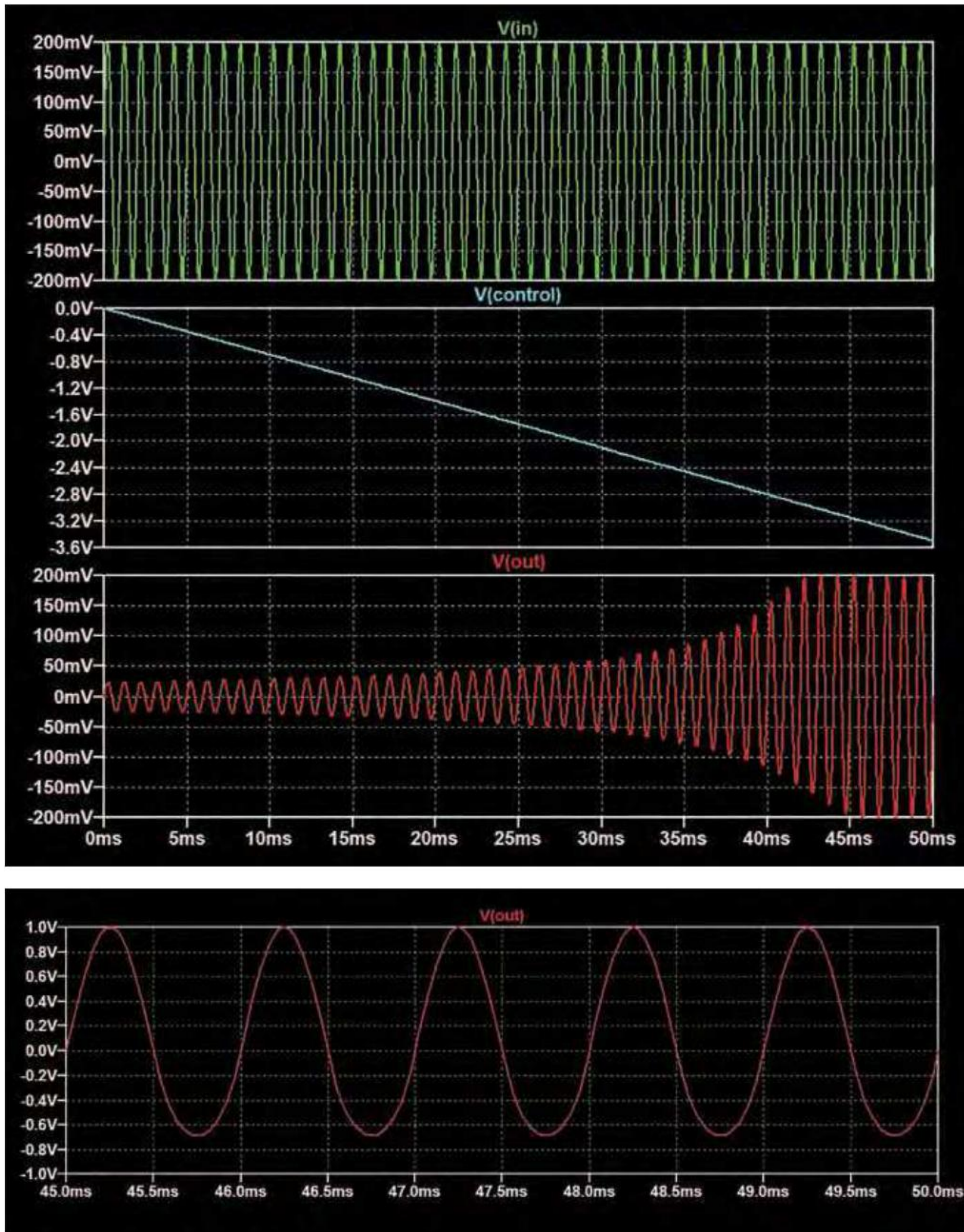


Fig.8. Distortion on the output from the JFET attenuator.

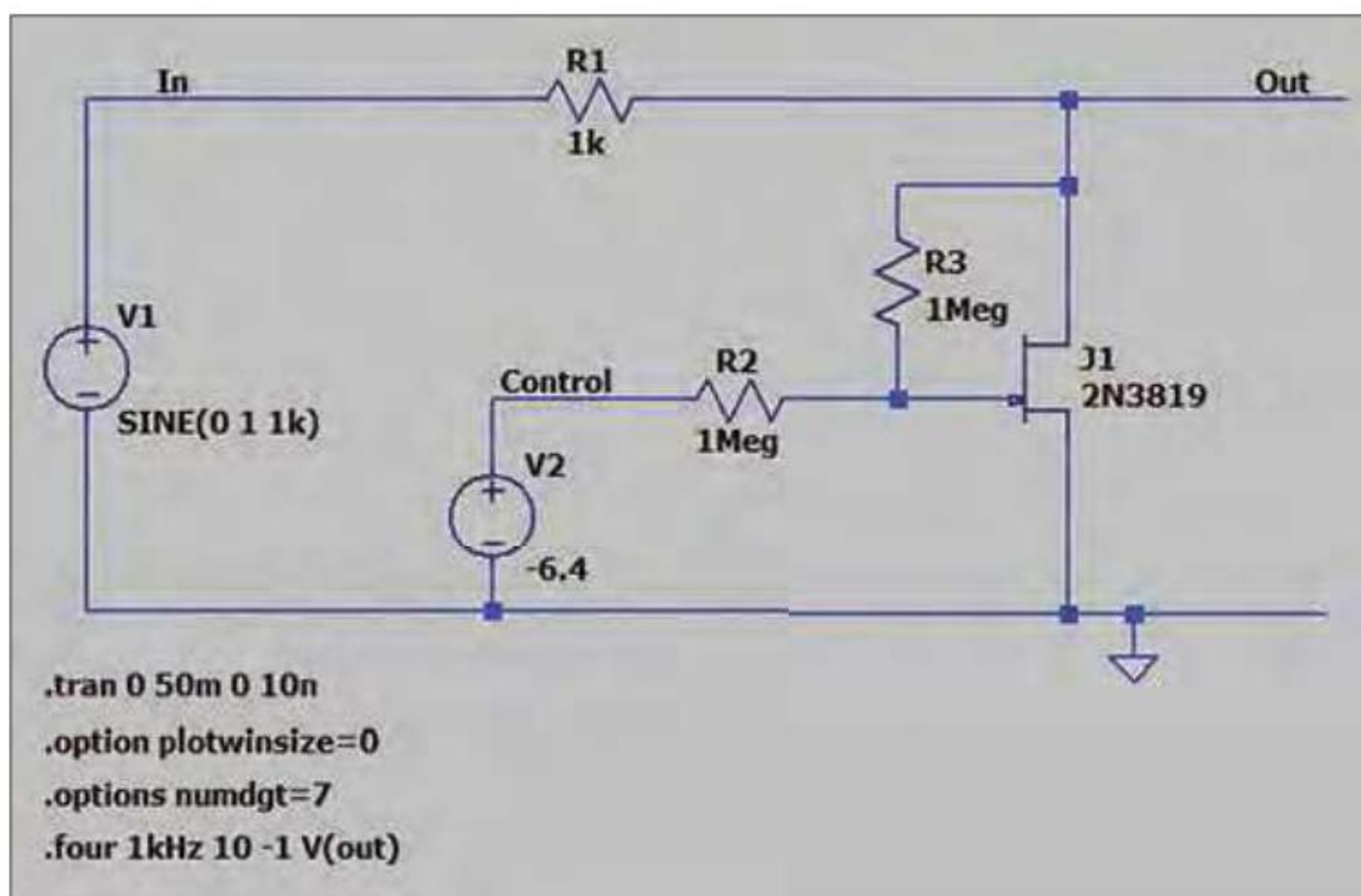


Fig.9. LTspice schematic for a JFET attenuator with feedback.

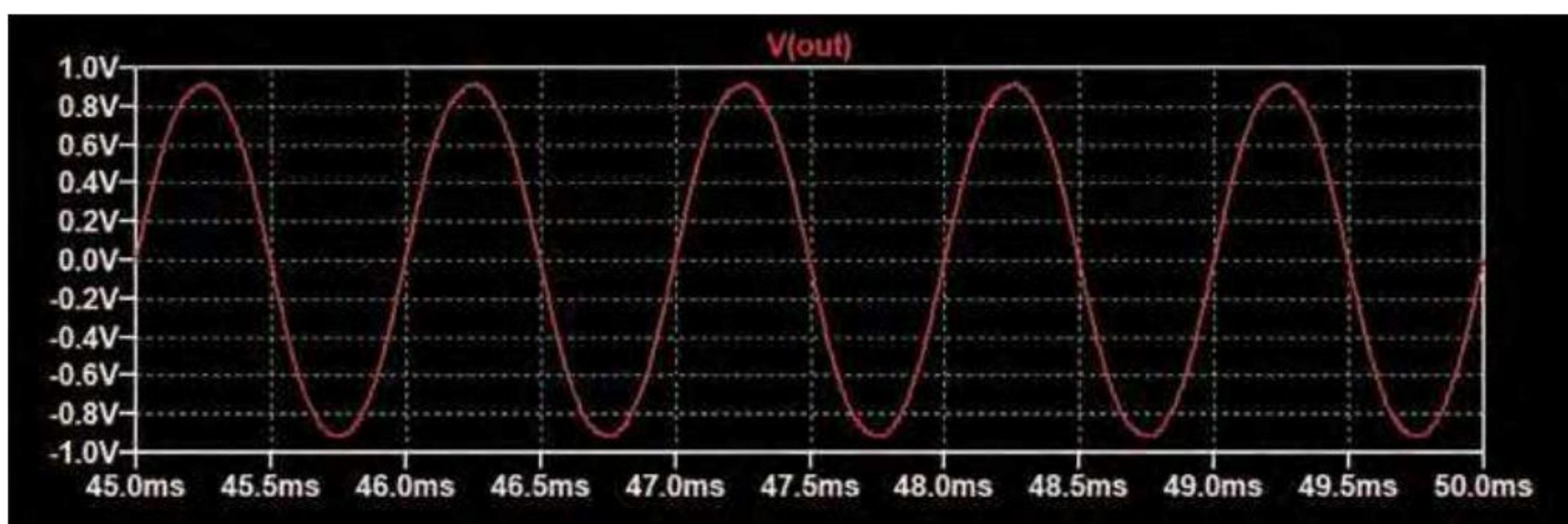


Fig.7. Results from LTspice JFET attenuator circuit in Fig.6.

so we will not repeat the details here. If this analysis is not required, the time step can be increased and the three directives removed to save time and file space.

The results of simulating the circuit in Fig.6 are shown in Fig.7. The input is a constant 200mV peak sinewave, and output follows this waveform at an amplitude set by the control voltage. Unlike the control voltage ramp, the envelope of the output amplitude is not a straight line – the control voltage to output amplitude is not a linear relationship. The output reaches its maximum value (equal to the 200mV input level) for control voltages beyond about -3.2 V, but note the waveform is not symmetrical, particularly at larger amplitudes, above about 100mV. This is due to the nonlinear resistance which does not vary symmetrically about zero drain-source voltage (see Fig.2). For low control voltages there is relatively little variation in output voltage with control voltage, so a more limited control voltage range than 0 to -3.5V may be better in practice than the full range shown here.

The minimum output signal, when the control voltage is zero, is about 23mV (this can be measured by zooming in on the initial part of $V(out)$ and using the cursors). By rearranging the potential divider equation as follows:

$$r_{DS} = R_1 \left(\frac{v_{out}}{v_{out} - v_{in}} \right)$$

we can find r_{DS} at this point as $1000 \times 23/(200 - 23) = 130\Omega$, which matches with the value for $V_{GS} = 0$ in Fig.2.

Distortion

Although the amplitude envelope (peaks of $V(out)$), shown in the bottom pane) looks asymmetrical in Fig.7, distortion is not particularly visible to the eye when zooming in on the sinusoidal waveform. If we increase the input to 1V it is more clearly seen – see Fig.8. The LTspice harmonic distortion analysis reports 10% THD for this signal (View > SPICE Error Log from the menu). The simulation was run with the control voltage V_2 source changed to a fixed DC value of -3.2 V rather than the PWL ramp setup in Fig.6.

As mentioned last month, distortion can be reduced by feeding back 50% of the drain-source voltage to the gate. This is achieved using a pair of resistors which form a potential divider. The resistors used for the feedback must be large to prevent loading. Since the gate has a very high effective input resistance, a feedback network using large resistors will not itself be loaded by the gate. Applying the feedback to the circuit in Fig.6 results

Fig.10. Output from the JFET attenuator with feedback (circuit in Fig.9). Distortion is reduced compared with that seen in Fig.8.

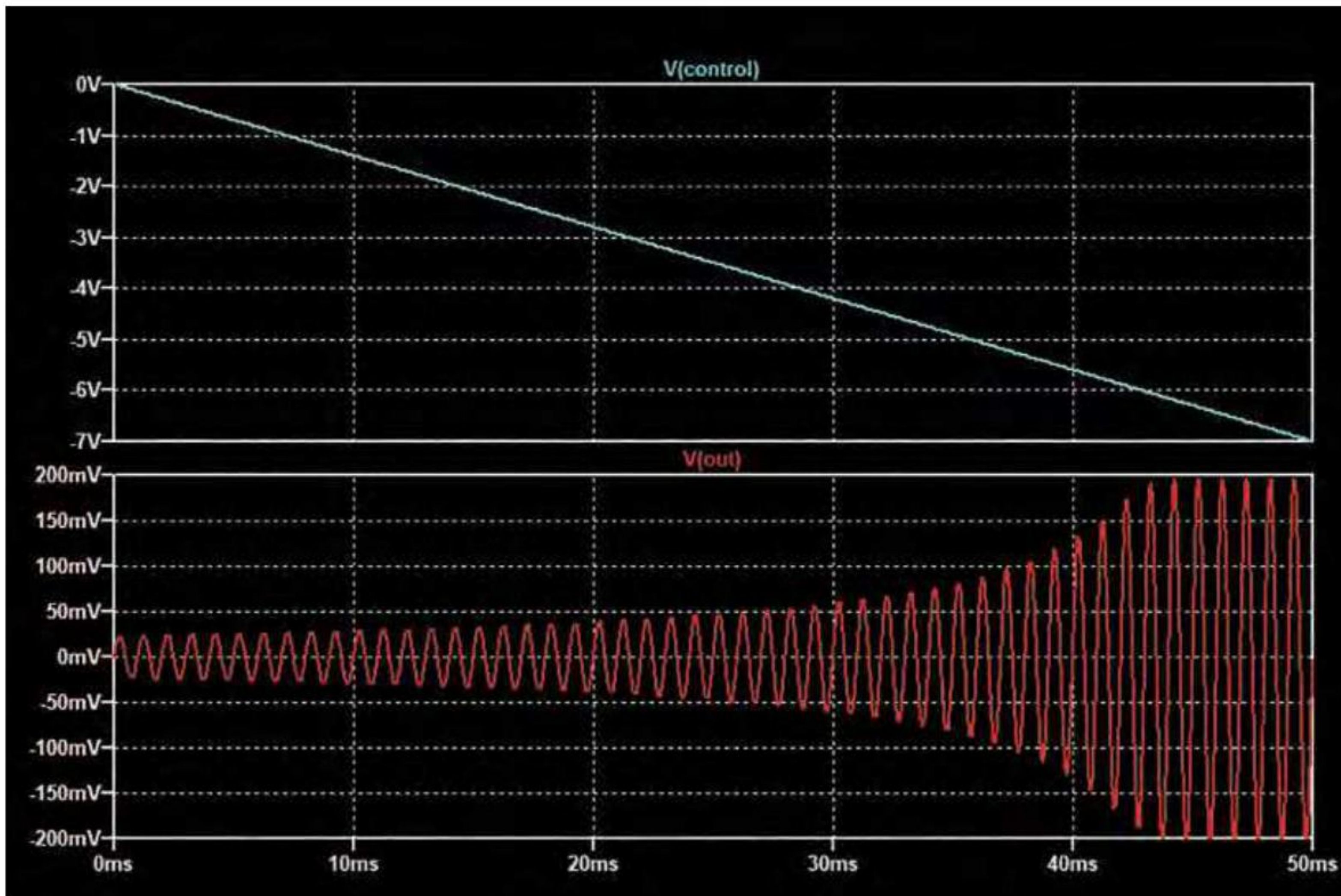


Fig.11. Results from Fig.9 with a 200mV input and 0 to -7V control voltage ramp.

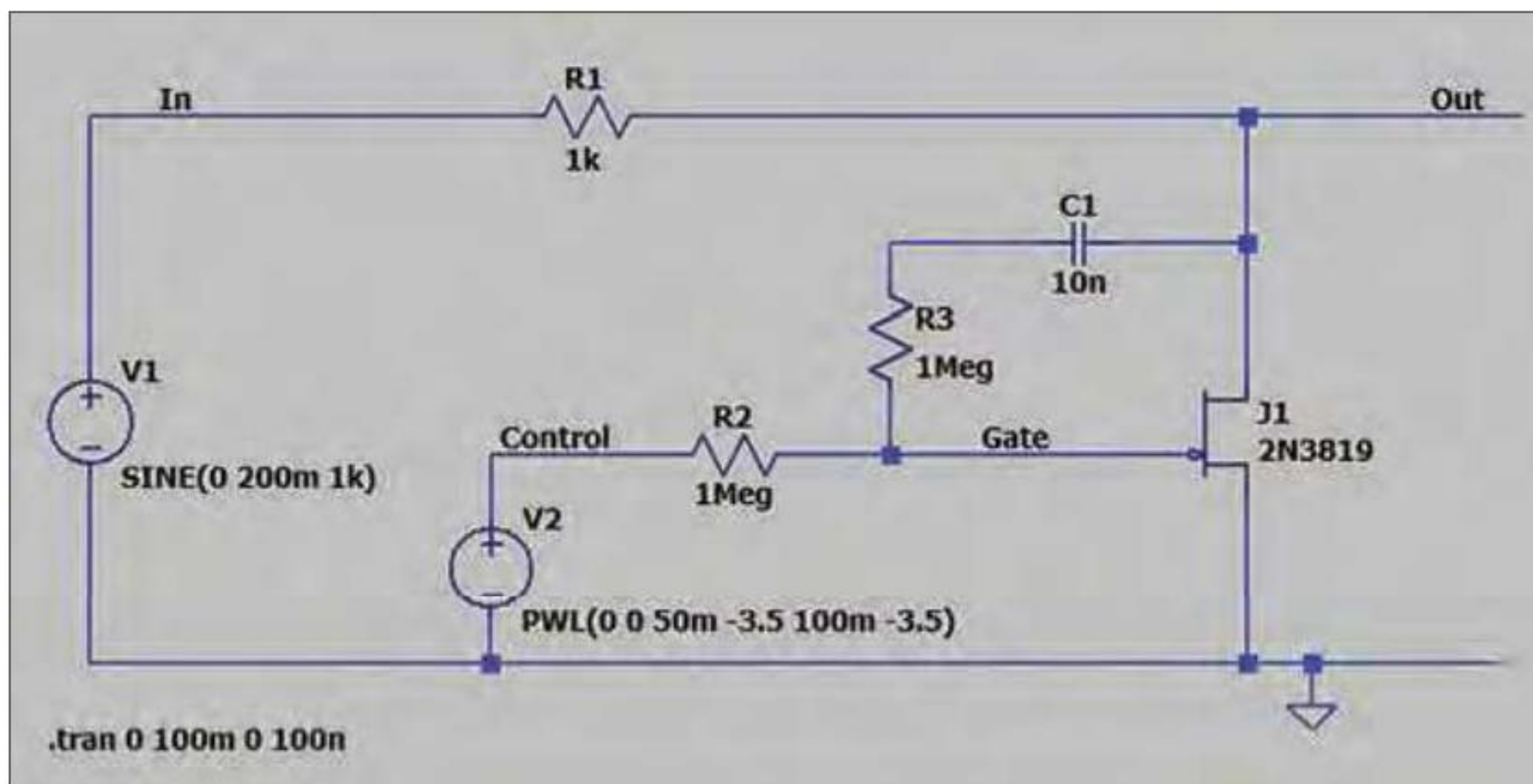


Fig.12. JFET attenuator with capacitively coupled feedback.

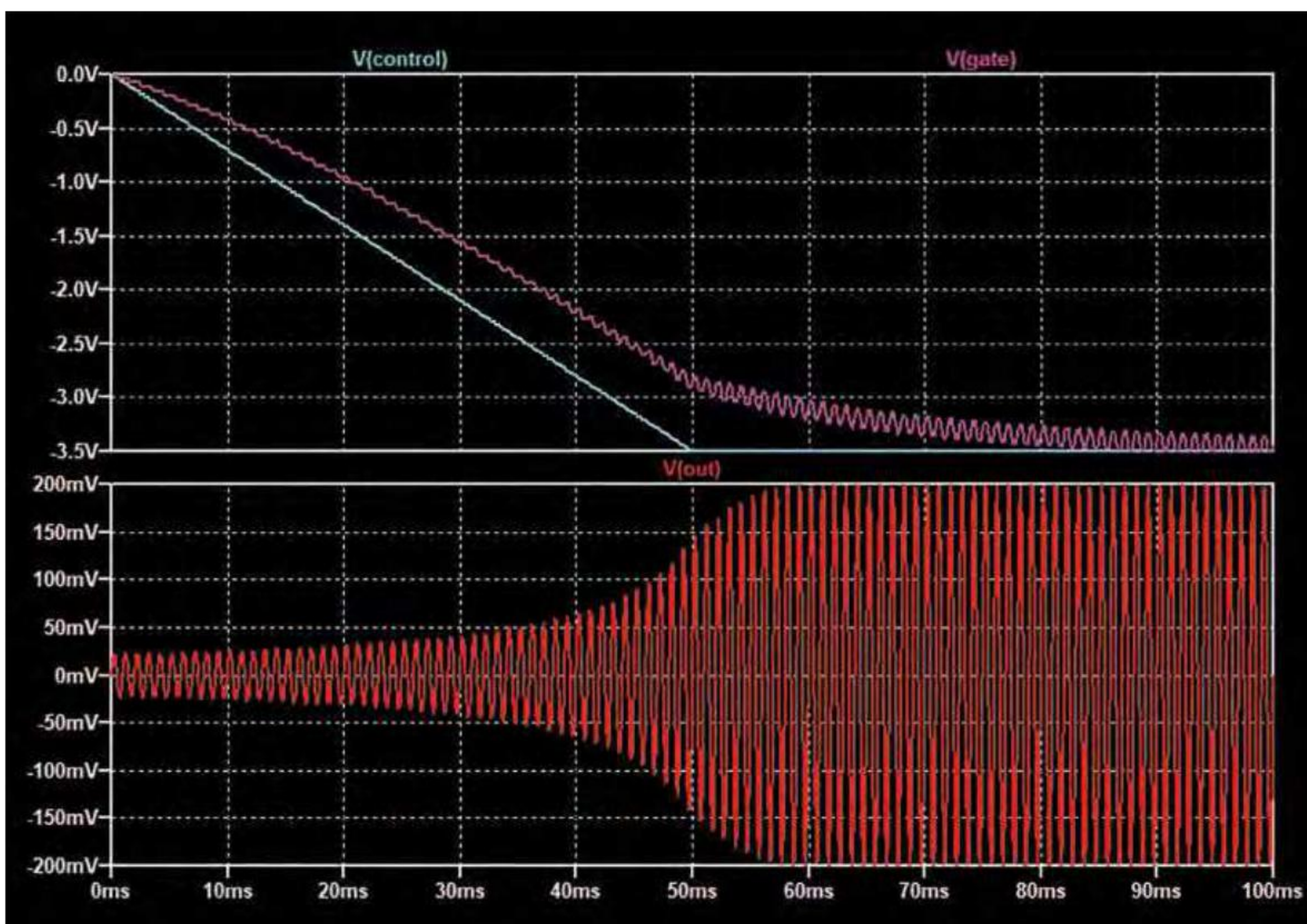


Fig.13. Simulation results for the circuit in Fig.12.

in the circuit in Fig.9 (this is configured with a fixed rather than ramped control voltage, but this is easily changed). To achieve the same output level as shown in Fig.8 the control voltage was doubled to -6.4 V, the potential divider formed by R_2 and R_3 halves the control voltage as well as providing feedback of 50% of the V_{DS} signal. The output, under similar conditions to those for Fig.8, is shown in Fig.10 – distortion is far less visible and calculated by LTspice to be 2.7%.

We can also run the control voltage ramp for this circuit, changing V_1 back to 200mV and using a final control voltage of -7V to account for the dividing effect of the feedback resistors (V_2 is set to PWL (0

0 50m -7)). The results are shown in Fig.11. The output amplitude range is the same as seen in Fig.7, but the envelope is more symmetrical.

Feedback

Only the signal itself needs to be fed back in order to reduce distortion (not any of the DC level on the drain). This can be achieved by capacitively coupling the feedback, as shown in Fig.12. The coupling capacitor and large feedback resistance have a long time constant. For the circuit in Fig.12, with $R = 2\text{M}\Omega$ and $C = 10\text{nF}$, the time constant $RC = 20\text{ms}$, so the capacitor will take around 100ms (5RC) to fully respond to relatively fast changes in the control voltage. The control voltage in the circuit in Fig.12 is configured like that in Fig.6 – it ramps to -3.5V. The doubled voltage used in the circuit in Fig.9 is not required because the DC is blocked by the capacitor in the feedback, so there is no divider effect with respect to the DC or slowly changing control voltage.

The results from simulating the circuit in Fig.12 are shown in Fig.13. The actual attenuation control signal is the voltage at the JFET gate – this is shown as the magenta trace on the upper plot pane. The feedback signal can be seen on top of the DC gate voltage. The DC voltage change on the gate lags behind the input control voltage, and, as noted above, takes around 100ms to reach the final control voltage level. The shape of the amplitude envelope in the lower pane is different from that in Fig.7 and Fig.11 in the first 50ms

(time range in Fig.7 and Fig.11) because the gate voltage no longer exactly follows the control voltage. Compared with Fig.7, the feedback reduces the asymmetry (as also seen in Fig.11).

If a step change is applied to the control voltage the gate voltage will step by half the control step and then follow the capacitor charging curve. The slow response of the circuit to control voltage changes may be a problem in some applications. Fast changes in control voltages may also couple to the output.

Adding op amps

JFET attenuators are commonly used in conjunction with op amp amplifiers to buffer the output and

provide gain and possibly buffer the input as well. An example is shown in Fig.14. This has a unity buffer using U1 on the input – which is useful here as the combined impedance of R_1 and the JFET is quite low and might load the source connected to the input. The output from the JFET attenuator is amplified by a non-inverting op amp amplifier (using U2) with a gain of 10 ($= 1 + 9\text{k}/1\text{k}$). When the control voltage is at or beyond -3.2 V the full input is passed to the output, so the maximum gain of the whole circuit is 10. The maximum attenuation occurs at minimum r_{DS} , which in this case was found in our discussion above to be 130Ω , giving an attenuation of $130/(1000 + 130) = 0.115$ (using the potential divider formula). The minimum gain of the whole circuit is therefore: $0.115 \times 10 = 1.15$

If we add an amplifier to the output of the JFET attenuator, then we can use the op amp's output as the source of the feedback signal to reduce the distortion. The op amp's low output impedance means that we can use smaller resistor values, which reduce the time constant of the feedback circuit, and reduce control voltage coupling to the FET drain as there is no longer a connection there via the feedback network. Fig.15 shows an LTspice schematic based on Fig.14, with the feedback supplied from the op amp's output. We need to feed back 50% of the drain signal, but this has been amplified by ten at the op amp's output, so the feedback from the op

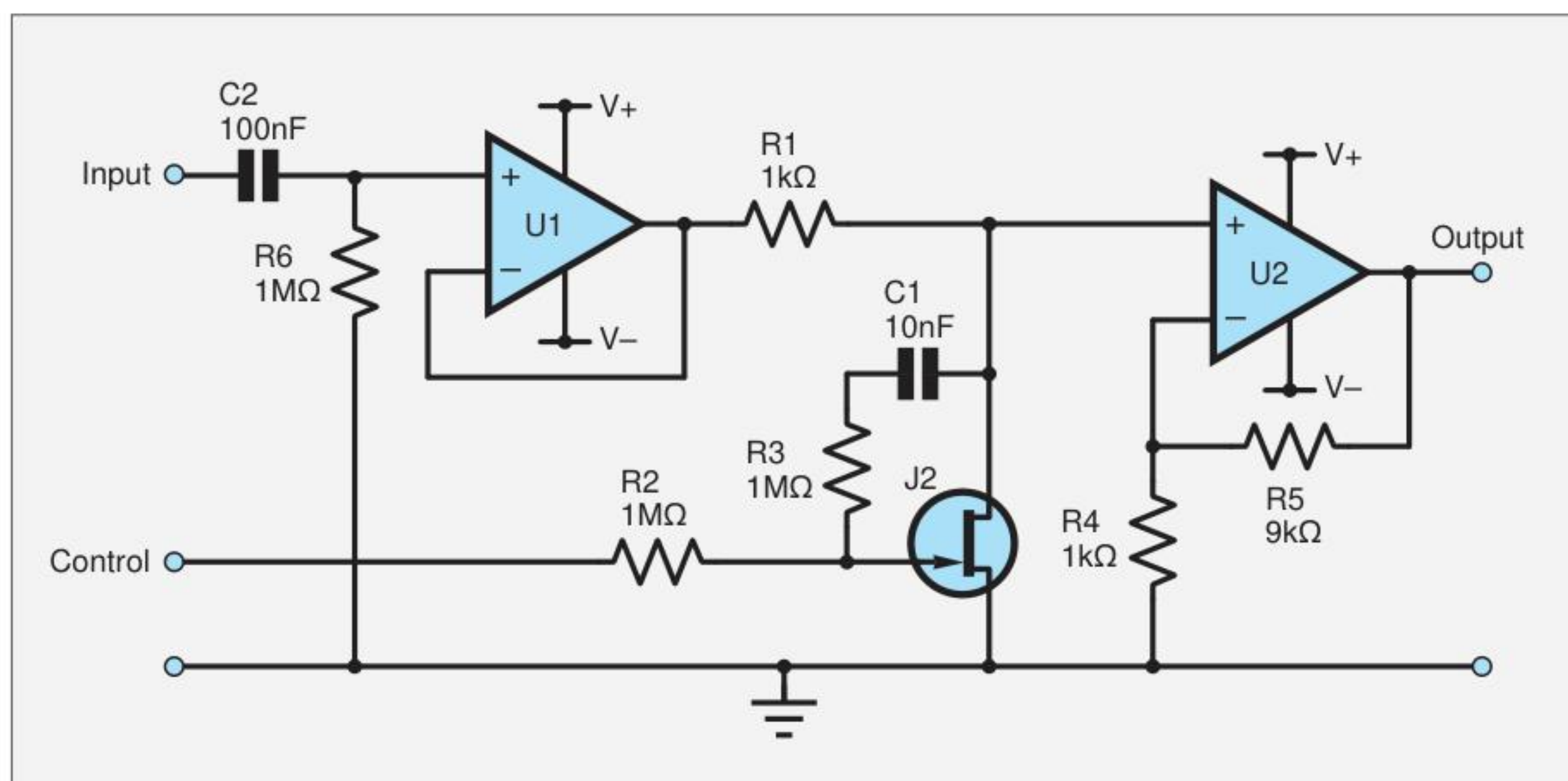


Fig.14. Example voltage-controlled amplifier based on a JFET attenuator.

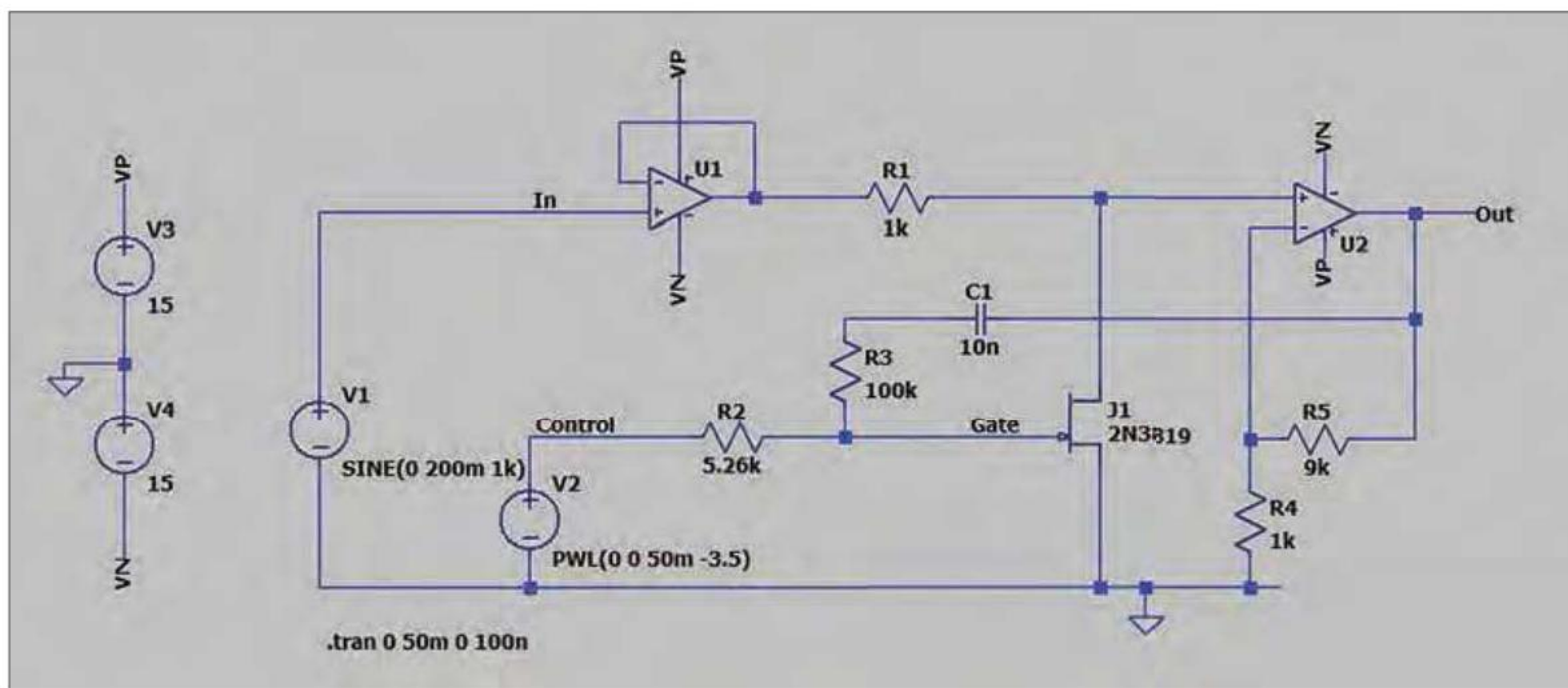


Fig.15. using the op amp's output for the JFET attenuator feedback signal.

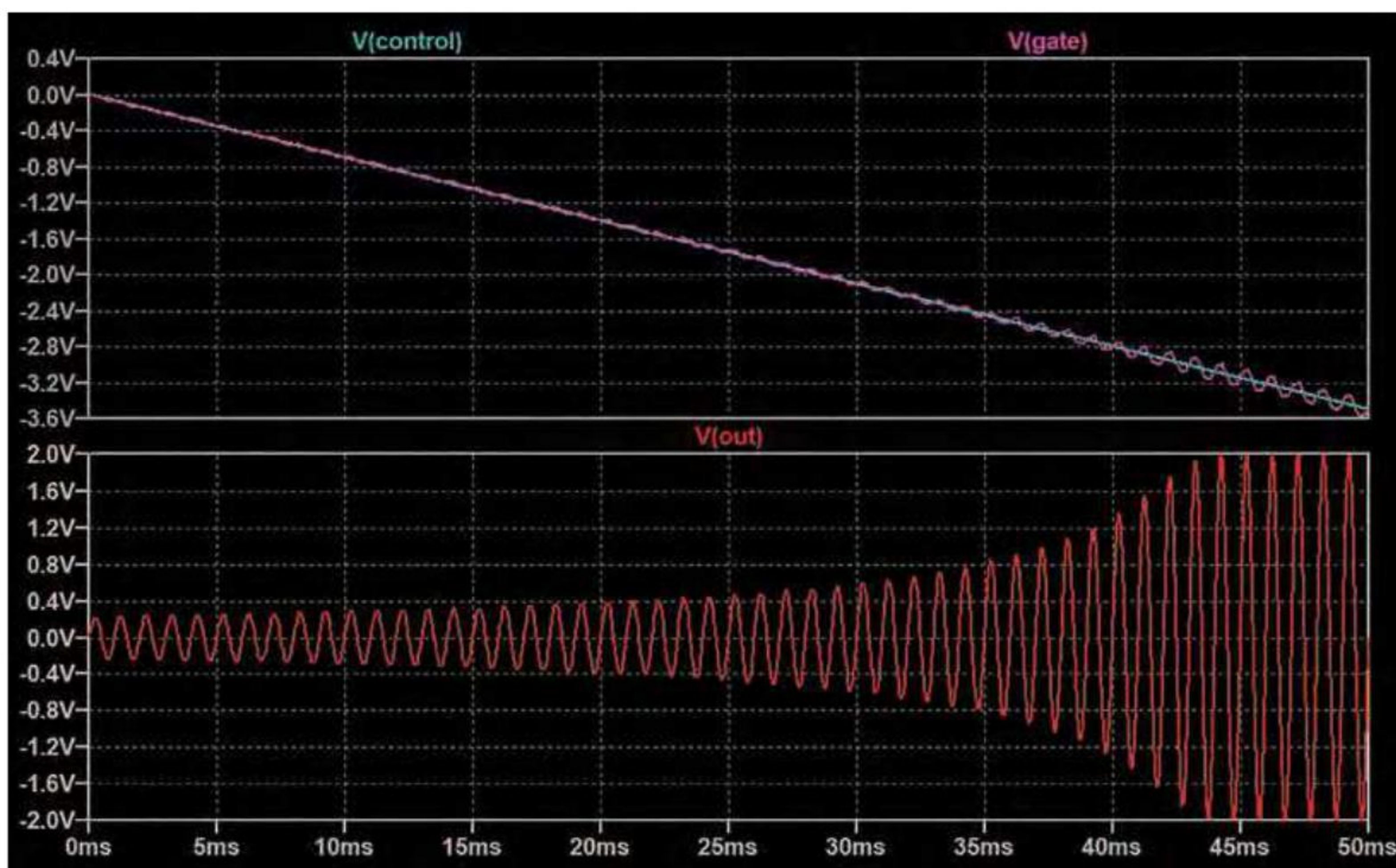


Fig.16. Simulation results from the circuit in Fig.15.

amp in this circuit has to be 0.05 of its output. The potential divider formed by R_2 and R_3 needs to be configured to attenuate the output by this factor. For the values used, we have $5.26\text{k}/(100\text{k} + 5.26\text{k}) = 0.4997$, which is very close. The feedback needs to be as close to 50% as possible to minimise distortion. Simulation results are shown in Fig.16, where it can be seen that the

gate voltage tracks the control voltage ramp, unlike in Fig.13.

Simulation files

Most, but not every month, LTSpice is used to support descriptions and analysis in *Circuit Surgery*. The examples and files are available for download from the *PE* website.

Make it with Micromite

Phil Boyce – hands on with the mighty PIC-powered, BASIC microcontroller

Part 40: Simple PicoMite GPS tracker

This month, we will demonstrate how easy it is to build a simple GPS tracker based around a PicoMite. To do this, we will connect a low-cost Pico GPS module to a *PicoMite Backpack*. The GPS module that we will use in this article is the Waveshare Pico-GPS-L76X (see Fig 1) – however, you could substitute this with any other model of Pico (or non-Pico) GPS receiver with only minor changes to the program code (and possibly the physical connections). There are three main reasons for choosing this specific GPS module, it is:

1. Cheap (approx. £15, incl magnetic GPS antenna mount)
2. Available from many online suppliers
3. Plug-and-play, so no wiring or soldering is required.

We will use the 2.8-inch version of the *PicoMite Backpack*, which incorporates the Waveshare Pico-ResTouch-LCD-2.8 module (discussed in *Part 38*). Many other screens could be used, but we have chosen this one since not only does it have a suitable pixel-resolution for displaying lots of GPS data, but also it incorporates an onboard micro-SD socket, which is useful for saving logged GPS data to a micro-SD card.

The GPS tracker program code is easy to build thanks to MMBASIC's built-in set of GPS commands. So, grab yourself these three modules (or equivalent) and let's begin.

Setting up the PicoMite Backpack

First, you need to set up a *PicoMite Backpack* with the Waveshare Pico-ResTouch-LCD-2.8. If you already have this *BackPack* set up then simply jump to the next section (*GPS module overview*); however, in case you missed *Part 38*, we will quickly describe the necessary steps.

1. Download the latest PicoMite Firmware (for free) from: <https://geoffg.net/picomite.html> (Note: scroll to the 'Downloads' section at the bottom of the page and click on the 'DOWNLOAD' button for: **PicoMite firmware V5.07.0x** (includes the manual). Remember to 'Extract all' to unzip the folder's contents.
2. Install the **PicoMiteV5.07.0x.uf2** Firmware file (from step 1) into the Pico module. Refer to *Make it with Micromite, Part 37* or the *Getting Started* section in the *User Manual* from step 1 for details on how to do this.
3. Connect the Waveshare Pico-ResTouch-LCD-2.8 display module. You can either use an expander board (recommended),



Fig 1. The low-cost Waveshare Pico-GPS-L76X is designed for use with the Pico. This module has both pins and sockets, enabling us to sandwich it in a stack between the PicoMite and a display module, thus creating a simple GPS Tracker.

or plug the display module directly into the PicoMite. Note that if you connect them directly together then you will need to separate them again when you insert the GPS module later. The GPS module is sandwiched between the PicoMite and the display module, so an expander board makes it a little easier to initially set things up – see Fig 2.

4. Connect the PicoMite to your preferred terminal app (eg, TeraTerm), and configure the following OPTIONS:

```
OPTION CPUSPEED 252000 (to run the PicoMite at 252MHz)
OPTION SYSTEM SPI GP10,GP11,GP12 (configure the SPI bus)
OPTION LCDPANEL ST7789_320,L,GP8,GP15,GP9,GP13
    (configure the display module)
GUI TEST LCDPANEL (check the screen is set up correctly)
OPTION TOUCH GP16,GP17 (configure the touch)
GUI CALIBRATE (calibrate the touch)
GUI TEST TOUCH (check the touch calibration)
OPTION SDCARD GP22 (configure the micro-SD card)
```

The above is just a summary of the required configuration to create a *PicoMite Backpack*. If you have any issues, or would like to configure a different display module, then please refer to the *User Manual* (or read *Make it with Micromite, Part 38*).

Micromite code

The code in this article is available for download from the October 2022 page of the *PE* website.



Fig 2. By using an expander board, it is much easier to connect the PicoMite, display module, and GPS module to initially set up the GPS Tracker. Note the orientation of each module.

GPS module overview

The Waveshare Pico-GPS-L76X GPS is a low-cost, plug-and-play module that is widely available. It has useful benefits such as fast positioning (with battery back-up), high accuracy, low power consumption and various LEDs for indicating the modules operating status. A close-up of both sides of the module is shown in Fig.3.

Like most other GPS modules, it has UART for (serial) communication, with a selectable baud rate of between 4800 and 115200bps (9600bps by default). This makes it easy to connect to the PicoMite since the program code just needs to communicate via an MMBASIC COM port. All we need to

know is the relevant pin numbers used for serial transmit (Tx) and serial receive (Rx). Refer to Fig.4 for a detailed pinout of the Pico-GPS-L76X GPS module – you will see that only four connections are used.

Note that there is one small disadvantage of this module – the onboard battery holder supports an ML1220 rechargeable cell. These are hard to source; however, the good news is that a battery is not essential; it just means that on power up the GPS module takes a bit longer to get the initial satellite fix (typically between one and two minutes). (If you find a source of the ML1220, then do please drop me an email with the details.)

Connecting the GPS module

If you use an expander board, then simply insert the GPS module into any available header. It is important to plug it in the right way round – refer to Fig.2 to see the correct orientation.

The alternative is to create a stack of boards. To do this, you will first need to carefully separate the PicoMite from the display module, and then insert the GPS module between them. Again, it is important to get the GPS module the right way round, so refer to Fig.5 to see the correct stack orientation.

Once the GPS module is installed, carefully screw the antenna into the larger end of the supplied adaptor, and then insert

the smaller end of the adaptor into the socket on the GPS module (item number 3 in Fig.3). Ensure that you position the antenna so that it has a good line of sight to the sky. This is so it stands a better chance of seeing multiple GPS satellites, which in turn means it will receive a better signal containing more accurate data.

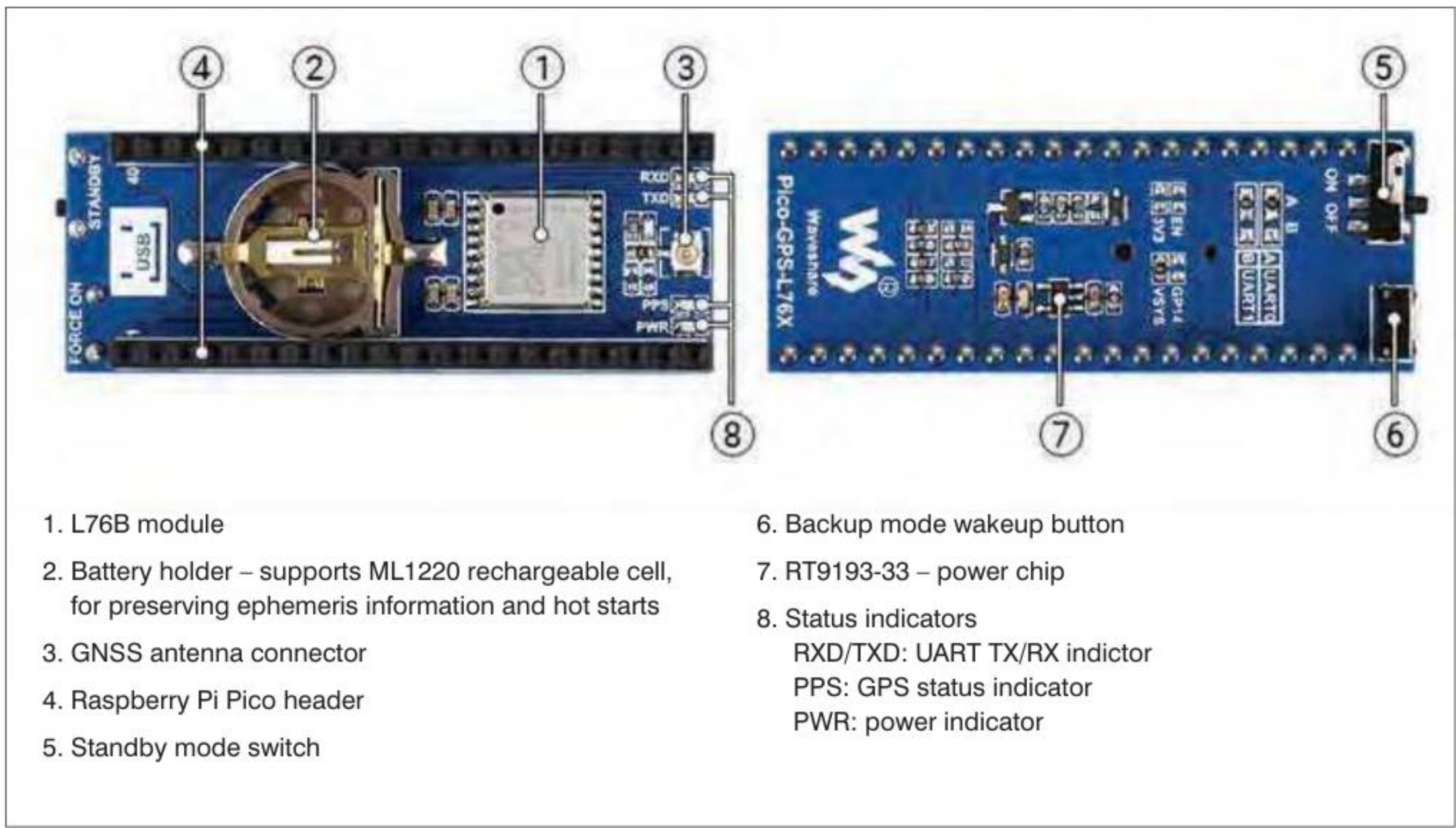


Fig 3. Top and bottom view of the various on-board elements of the Waveshare Pico-GPS-L76X.

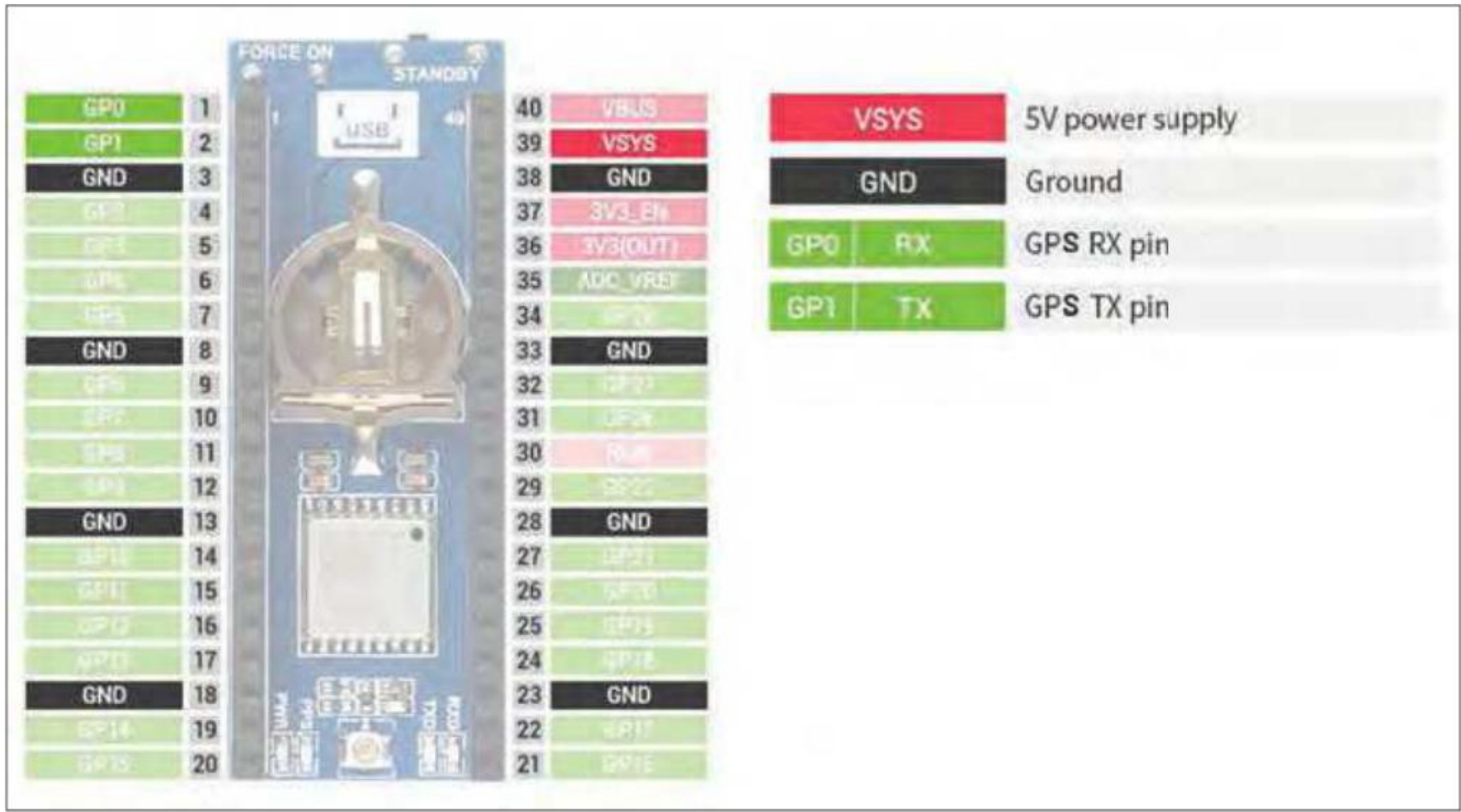


Fig 4. Pinout of the Pico-GPS-L76X module. Just four pins are required, two for power, and two for serial communication. Note that the GPS Rx pin is on GP0 (PicoMite COM1 Tx pin), and GPS Tx is on GP1 (PicoMite COM1 Rx pin).

GPS data

Before we explore MMBASIC's built-in GPS commands, let's first look at the format of GPS data. Fig.6 shows a snapshot of actual raw data grabbed directly from the Pico GPS module (via a USB-to-serial module, and displayed in TeraTerm which was set to a baud rate of 9600). GPS raw data is made of multiple 'sentences', each one containing various GPS data. Typically, a set of sentences is output every second from the GPS receiver. The type of each sentence is indicated by the characters at the start of the line (after the initial '\$'). For example, the second line in Fig 6 is a GNGGA sentence (technically referred to as a 'Global Positioning System Fix Data' sentence). A GNGGA sentence contains useful GPS data such as time, latitude, longitude, number of satellites and altitude. The content of this (and other) sentences is well documented online (a worthwhile reference is: <http://aprs.gids.nl/nmea/>) so we won't go into further detail here. Note that it is not essential to understand the exact format of sentences for our tracker, we are just providing a reference for readers who want to read more about the specific details. So how do we go about extracting the relevant elements of GPS data in MMBASIC?

In earlier versions of the Micromite firmware, serial communication with



Fig 5. Here, the PicoMite, GPS and display modules can be seen stacked together. Note the correct orientation of each module.

a GPS module meant receiving serial data into a COM port input buffer. The program code then searched for the start of a sentence (indicated by a '\$' character), and/or the end of a sentence (Carriage Return and Line Feed). Once detected, the program code would then work through the first few bytes in the sentence to check the type of sentence (and hence, what data follows). In brief, the program code looks for a required sentence match (for example 'GNGGA'). Only when the required sentence type is found can the relevant data be extracted in a meaningful way. This whole process is quite complex to code, but it is possible.

The great news is that everything has now been made so much easier with the PicoMite Firmware thanks to the set of GPS commands (or more specifically, GPS functions). These remove all the programming complexities since all you now need to do is use the appropriate parameter, and the relevant data will automatically be returned. For example, to extract the time you would use GPS (Time); likewise, GPS (Satellites) will return the number of satellites being detected by the GPS antenna.

However, before using any of the GPS functions, it is important to include the following two lines of code somewhere near the start of the program:

```
SETPIN GP1,GP0,COM1
OPEN "COM1: 9600,256" As GPS
```

The first line defines the PicoMite's Rx pin and Tx pin for use with serial port COM1 – in Fig.4 you can see these are GP1 and GP0 respectively.

The second line opens up COM1 for use with a serial GPS receiver. The parameters define the baud rate as 9600bps, and a receive buffer size of 256 bytes.

```
$GNVTG,222.20,T,M,0.00,N,0.00,K,A*23
$GNGGA,094237.000,5127.0422,N,00026.1691,W,1.10,1.00,20.4,M,47.1,M,0.0,0000.00
$GPGSA,A,3,22,10,27,01,21,08,32,14,0.0,1.32,1.00,0.87*06
$BDGSA,A,3,06,09,0.0,1.32,1.00,0.87*12
$GPGSV,3,1,12,21,84,321,26,08,58,162,34,01,56,279,28,32,33,085,38*77
$GPGSV,3,2,12,14,29,300,28,22,27,113,37,10,24,051,34,03,24,214,19*70
$GPGSV,3,3,12,27,22,143,29,17,08,310,18,24,01,018,,43,,*4E
$BDGSV,1,1,02,06,18,063,29,09,16,078,27*6F
$GNGLL,5127.0422,N,00026.1691,W,094237.000,A,A*50
$GNRMC,094238.000,A,5127.0422,N,00026.1691,W,0.00,222.20,210822,0.0,A*63
$GNVTG,222.20,T,M,0.00,N,0.00,K,A*23
$GNGGA,094238.000,5127.0422,N,00026.1691,W,1.10,1.00,20.4,M,47.1,M,0.0,0000.00
$GPGSA,A,3,22,10,27,01,21,08,32,14,0.0,1.32,1.00,0.87*06
$BDGSA,A,3,06,09,0.0,1.32,1.00,0.87*12
$GPGSV,3,1,12,21,84,321,26,08,58,162,34,01,56,279,28,32,33,085,38*77
$GPGSV,3,2,12,14,29,300,28,22,27,113,37,10,24,051,34,03,24,214,20*7A
$GPGSV,3,3,12,27,22,143,29,17,08,310,18,24,01,018,,43,,*4E
$BDGSV,1,1,02,06,18,063,29,09,16,078,27*6F
$GNGLL,5127.0422,N,00026.1691,W,094238.000,A,A*5F
$GNRMC,094239.000,A,5127.0422,N,00026.1691,W,0.00,222.20,210822,0.0,A*62
```

Fig 6. A sample of GPS raw data as it outputs from the GPS receiver. Note that each sentence starts with a '\$' character, followed by the type of sentence, and then all the GPS data follows to the end of the line.

MMBASIC's GPS functions

With the above two lines near the start of the program code, we are then able to use any of the GPS functions. The most important function is **GPS (VALID)**. This function should be used before any of the other GPS functions are used to ensure that any subsequent data requested is valid. It returns a value of 0 for invalid data (triggered when a sentence's checksum value is incorrect), and a value of 1 for valid data (ie, the sentence's checksum value is as expected). Your program code just needs to check for a value of 1, then it can safely use the required GPS function(s) knowing that the returned data represents a true value.

The following is a list of the more common GPS functions available (all are used in our GPS Tracker code):

GPS (DATE) Returns the normal date string corrected for local time; eg, 28-08-2022

GPS (TIME) Returns the normal time string corrected for local time; eg, 12:22:53 – note that daylight saving is not taken into account and has to be adjusted in program code using (for example) the EPOCH command

GPS (SATELLITES) Returns number of satellites in view

GPS (LATITUDE) Returns the latitude in degrees as a floating-point number, values are negative south of the equator

GPS (LONGITUDE) Returns the longitude in degrees as a floating-point number, values are negative west of the Greenwich meridian

GPS (ALTITUDE) Returns the current altitude

GPS (SPEED) Returns the ground speed in knots as a floating-point number

GPS (TRACK) Returns the track over the ground (degrees true) as a floating-point number

GPS (FIX) Returns non-zero (true) if the GPS has a fix on sufficient satellites and is producing valid data

There are two further functions available for more advanced users (neither are used in our GPS Tracker code):

GPS (DOP) Returns DOP (dilution of precision) value

GPS (GEOID) Returns the geoid-ellipsoid separation

You can try any of the above at the command prompt to see what a function returns. Begin by typing these two lines:

```
SETPIN GP1,GP0,COM1
OPEN "COM1: 9600,256" As GPS
```

Next, type the relevant function at the command prompt, for example:

```
PRINT GPS (DATE)
```

You can then try the other functions without having to type the first two lines again. So continue with something like PRINT GPS (SATELLITES) to see the number of satellites.

Remember that in our program we should always check that GPS (VALID) returns a value of 1 (we have not used it at the command prompt as we are just demonstrating the output from the various GPS functions).

Tracker software

Now that we have all the hardware connected, it's time to load the GPS Tracker software into your PicoMite.



Fig 7. The GPS tracker program displays various GPS data on the 2.8-inch display. All data is also logged to the micro-SD card.

The file you need is **GPS_Tracker.txt** which is available for download from the October 2022 page of the *PE* website. Once installed, it is worth taking a quick look at the program code to see how it works. As usual, it is well commented so it should be easy to follow what is going on. In summary, the following steps occur:

1. COM1 is set up as a serial port for use with a GPS receiver
2. A welcome message is displayed briefly (it fades in, then fades out)
3. The value of GPS (VALID) is checked:
 - a. If 0 (invalid data), then grey out any current data shown on the 2.8-inch display and make the screen's border red
 - b. If 1 (valid data) then:
 - i. Extract various GPS data (date, time, satellites, lat, long, altitude, speed, tracking)
 - ii. Make the screen's border green
 - iii. Display the various GPS data on the 2.8-inch display (see Fig 7)
 - iv. Check if Time is different to last time:
 - If Time is still the same, then do nothing
 - If Time is different, then log GPS data to the SD card
4. Go to step 3

As can be seen from Fig 7, the basic GPS data is formatted onto the 2.8-inch display so that you can continually see what is happening in terms of received data. (Note that the data logged to the SD card is limited to a maximum of one record per second).

A useful test at this point is to mount the GPS set up in a vehicle, and then go for a drive with the purpose of gathering a good set of data on the SD card. Please do take all necessary precautions while driving – or put it another way, keep your eyes on the road and not on the GPS tracker's display! Once a set of data is obtained, remove the SD card from the display module, and insert it into a computer. Open the log file which will be named **trkDATA_yymmdd_hhmmss.csv** (but with the current date and time values) and you will be able to view the logged data.

You can use something like Google maps to plot the longitude and latitude co-ordinates to see the precise location plotted onto a map – doubtless some websites can plot all the data points in one go to show the path taken on your test drive (more on this next month).

That's it. You can see how everything works. Why not edit the program code to make your own custom version of the GPS tracker? Try adding some new features – here are a few ideas:

- Change the layout of the screen to show only the data you're interested in
- Add a 'logged-record' counter to indicate how many entries have been logged onto the SD card
- Add a parameter to the program code that determines how often data is logged to the SD card
- Limit logging to the SD card based on a change of position rather than logging every second
- Change the data logged to only include the fields you're interested in

- Add error checking; for example, when the SD card is removed (or is missing), show a warning message
- Make a covert tracker unit that does not require a display. Instead, use the PicoMite's green 'heartbeat' LED as a status indicator.

Next time

When I ordered the GPS module for this article, the supplier accidentally sent me a finger-print reader module instead. They let me keep it (and subsequently sent me the GPS module I had originally ordered). I've examined the finger-print reader's datasheet, and it seemed like something that could easily be connected to the PicoMite, so I challenged myself to see if I could get the PicoMite to communicate with the reader, and sure enough, the PicoMite easily interacted with it. However, the complex part is to get the hardware to learn different fingerprints, store the patterns internally, and then compare any finger (touched onto the reader) against the stored patterns and thus identify the user. Thankfully, all this intelligent functionality is built into the finger-print reader, but that means it is essential to have a thorough understanding of the reader's datasheet. Data communication between the PicoMite and the reader is quite complex and has to be performed in a very specific way for successful operation. Hence, it is all down to the PicoMite program code which is currently a work in progress. I hope next month to be able to show you how to integrate a low-cost finger-printer reader module into your next project – fingers crossed! Until then, stay safe, and have FUN!



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Max's Cool Beans

By Max the Magnificent



Flashing LEDs and other engineering temptations – Part 32

A long, long time ago in a place far, far away when I was sporting a much younger man's clothes, I was fortunate enough to see the *Police* play in Leeds (when I say 'Police,' I mean the band, not the West Yorkshire constabulary, although I'm sure they are a fine bunch of people). The *Police*'s music was very different to anything else at that time, being a unique style of rock influenced by punk, reggae, and jazz. Although there were only three members of the group – Sting (lead vocals, bass guitar), Andy Summers (guitar), and Stewart Copeland (drums, percussion) – they managed to completely fill the sound space.

Message in a bottle

Just saying their name brings so many songs to mind: *Roxanne*, *Walking on the Moon*, *Message in a Bottle*... The reason all this comes to mind is that I just received a message from a reader who we'll call Andrew (because that's his name). (Did you see what I did there? Just call me the 'King of Segue.') In his message, Andrew—who is employed as a design and technology technician at a high school in Leominster, Herefordshire – spoke as follows:

'Hi Max, I read with great interest the part of your *Cool Beans* column discussing servo motors in the August 2022 issue of *Practical Electronics*. This took me back to 1989 when I was studying for my HND in Electronics and Computer Technology at what was then Birmingham Polytechnic. I constructed a steerable solar panel using model servo motors given to me by my lecturer. They were very similar to those shown in your article. In those days, we

had copious quantities of 741 operational amplifiers (op amps) and classic 555 timers. My panel had two axes of motion: left/right and up/down. Working back from the servo motors, I employed 555 timers that were pulse-width modulated at 50Hz. These were controlled using four light-dependent resistors (LDRs) mounted in the corners of a cross, which was itself mounted on the steerable panel. If the panel was not pointing directly at a light source (eg, the Sun), a shadow was cast on one or more of the LDRs, causing comparator circuits provided by the 741 op amps to generate corresponding pulse-width information. The idea was for the panel to move until none of the LDRs were in shadow and each pair of LDRs received the same amount of light, thereby indicating that the panel was pointing towards the light source. This is a long time ago now and I'm relying on my memory from 1989 (to find my notes from that time would require a serious amount of digging). One thing I remember is using several resistance decade boxes to fine tune the system. I also distinctly remember that, when I switched the system on for the first time, the panel moved across and upwards, paused, and then started to hunt slightly (I was using only proportional 'P' control with no integral 'I' and no differential 'D'). It took me a few seconds to realise that the panel had moved to look at a fluorescent light mounted in the ceiling. I subsequently made a 'light wand,' which was basically an incandescent reflector lamp on the end of a stick. When I came to demonstrate my project, I moved around the room, the panel followed my wand, and the lecturer who assessed my project really liked it. Thank you for your great article and I look forward to the next one. Take care and best wishes, Andrew Moore.'

Well, if Andrew liked the August issue of *PE*, I hope the September issue featuring the amazing computer-aided-design (CAD) drawings created by my friend Steve Manley showing the insides of a servo (accompanied by our discussions of torque and gear trains and gear ratios) took his breath away.

Not 1, 2, or 3, but 4!

Speaking of the August and September issues, in the former we created a simple circuit and sketch (program) that caused our micro servo to sweep back and forth; in the latter, we extended this sketch to cause the servo to respond to turning a potentiometer (pot).

As you may recall from previous columns, when Steve and I first started out on our animatronic noggin project, I purchased a couple of preassembled Pan-and-Tilt Kits from Adafruit (<https://bit.ly/3cEYPoL>). These little scamps feature two SG-90 or SG-92 micro servos that are similar to the one we've been playing with (Fig.1). Using these servos, we can cause the assembly to pan from side-to-side and tilt up-and-down.

We also purchased some super-tasty JH-D400X-R4 4-axis joysticks, for which there are lots of suppliers on platforms like Amazon (<https://amzn.to/3RXl61d>). For the purposes of these discussions, however, I decided to splash the cash for a couple of miniature KY-023 joystick breakout modules (<https://amzn.to/3crXO38>). In addition to +5V and 0V (ground, or GND) connections, these little rascals have X, Y, and SW ('switch') outputs (Fig.2).

This month, we're going to use an Arduino Uno to read the X/Y values from these joysticks and use them to control the servos on our pan-and-tilt assemblies. Since we are using a lot of flying leads, along with a breadboard to 'glue' everything together, the result is a bit of a rat's



Fig.1. Pan-and-tilt using two micro servos (Image: Adafruit)



Fig.2. KY-023 joystick (Image: AZ-Delivery)

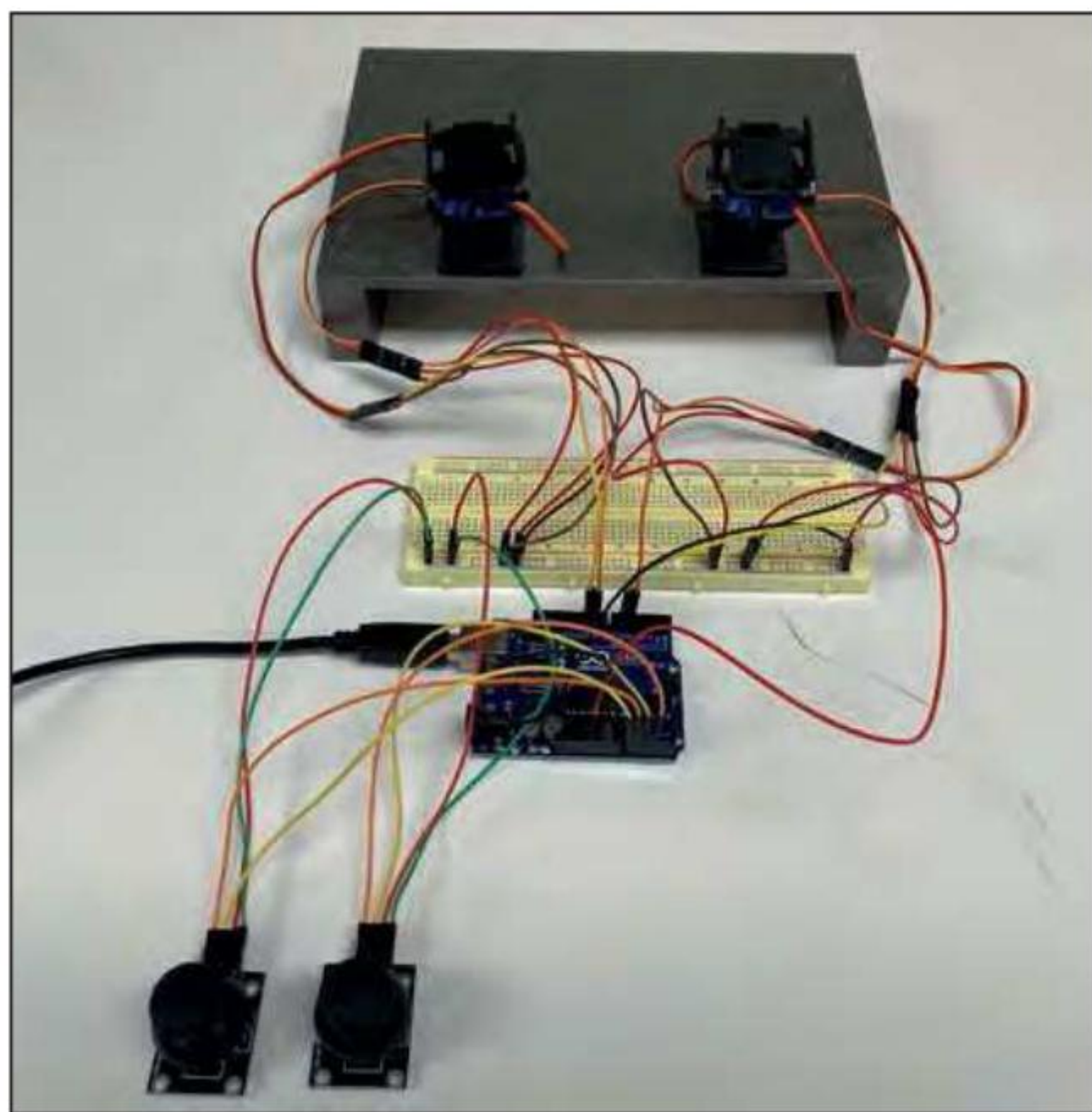


Fig.3. Test setup (joysticks at the front, pan-and-tilt assemblies at the back).

```

31 void loop()
32 {
33     int PotValLeftX = analogRead(PotPinLeftX);
34     int PotValLeftY = analogRead(PotPinLeftY);
35     int PotValRightX = analogRead(PotPinRightX);
36     int PotValRightY = analogRead(PotPinRightY);
37
38     PotValLeftX = map(PotValLeftX, 0, 1023, 0, 180);
39     PotValLeftY = map(PotValLeftY, 0, 1023, 0, 180);
40     PotValRightX = map(PotValRightX, 0, 1023, 0, 180);
41     PotValRightY = map(PotValRightY, 0, 1023, 0, 180);
42
43     ServoLeftTilt.write(PotValLeftX);
44     ServoLeftPan.write(PotValLeftY);
45     ServoRightTilt.write(PotValRightX);
46     ServoRightPan.write(PotValRightY);
47
48     delay(15);
49 }

```

Fig.4. Main servo code control loop.

nest (Fig.3), but that's all part of the fun of prototyping.

The program itself is just a slightly modified version of the code we discussed in my previous column (PE, September 2022). Instead of having a single analogue input connected to a single pot, we now have four of each. And instead of a single servo, we now have four of the little ragamuffins. The core of the code is shown in Fig.4.

First, we read all four of the values from our pots. Next, we use the Arduino's `map()` function to map the 0 to 1023 values from our pots onto the corresponding 0 to 180 values required by our servos. We then write these mapped values to the servos, wait for 15 milliseconds to give the servos time to respond, and then return to the beginning and do it all again. If you wish, you can download the full program to peruse and ponder at your leisure from (file **CB-Oct22-01.txt**) from the October 2022 page of the *PE* website (<https://bit.ly/3oouhbl>).

Oops!

To be honest, I'm usually a little cavalier when it comes to connecting together things like our servos and potentiometers. By this I mean that I don't spend a lot of time agonising over which of the X/Y joystick wires is connected to which of the analogue inputs. For example, if I move the joystick to the left or right and the servo assembly tilts forward or backward, or if I move the joystick forward or backward and the servo assembly pans to the left or right, then it's a matter of moments to swap the two analogue input pin assignments associated with this pot in the code.

Similarly, if I move a joystick to the left and the corresponding pan servo moves to the right, or if I push a joystick backward and the corresponding tilt servo leans forward, and either of these is opposite to

the action I wish to see, it's easy to fix this in the code. There are two obvious ways to do this. The first is to subtract the 0 to 1023 value read from the pot from 1023 prior to calling the `map()` function; the second is to subtract the 0 to 180 value generated by the `map()` function from 180.

Thanks for the memories

These days, when it comes to the memory subsystems we use in our computers and other electronic devices, we have become spoiled by all of the features and functions offered by semiconductor technologies. The options available to design engineers used to be much more limited. Although it is certainly possible to create memories using technologies like relays or vacuum tubes, the cost, power consumption and physical footprint of each bit soon makes your eyes water.

To get around this, the ancients came up with a captivating cornucopia of cunning concepts, such as the acoustic mercury delay line, which was invented by William Shockley in 1942, and first deployed in radar applications. Later, in the mid-1940s, J Presper Eckert developed the technology for use as memory in computers such as the EDVAC and the UNIVAC I. The idea was to use a piezoelectric transmitter to inject pulses at one end of a thin tube filled with mercury, and to use a piezoelectric receiver at the other end of the tube to detect the presence (or absence) of pulses after they had propagated across the tube. Individual pulses could be added into, or deleted from, the train as it was fed back into the transmitter. Although this may sound a tad 'Heath Robinson,' once the technology had matured, around 1,000 bits could be stored in a 5-foot-long delay line, which was jolly exciting at the time. Although these mercury delay lines were rather revolutionary, they had several disadvantages,

not least that mercury is toxic. But the biggest issue was the fact that they offered only sequential access to the data they contained, which means the system had to sit around twiddling its metaphorical thumbs waiting for the portion of the pulse train of interest to pass by.

Towards the end of the 1940s and the beginning of the 1950s, a new kid came to memory town in the form of tiny magnetic cores. The easiest way to wrap your brain around this is by means of a diagram (Fig.5).

There's much more to this than meets the eye, but it's simple enough if we don't dive into the weeds. Suppose we have a single core on a single wire. If we pass a pulse of current through the wire, and if that pulse is of sufficient strength, then we can magnetise the core in a certain way. We might consider this to represent a logic 1. If we later pass a similar pulse down the wire but in the opposite direction, we can flip the magnetic field in the core, and we might consider this to represent a logic 0.

Using a single wire is limiting because any cores on that wire will be magnetised in the same direction. However, suppose

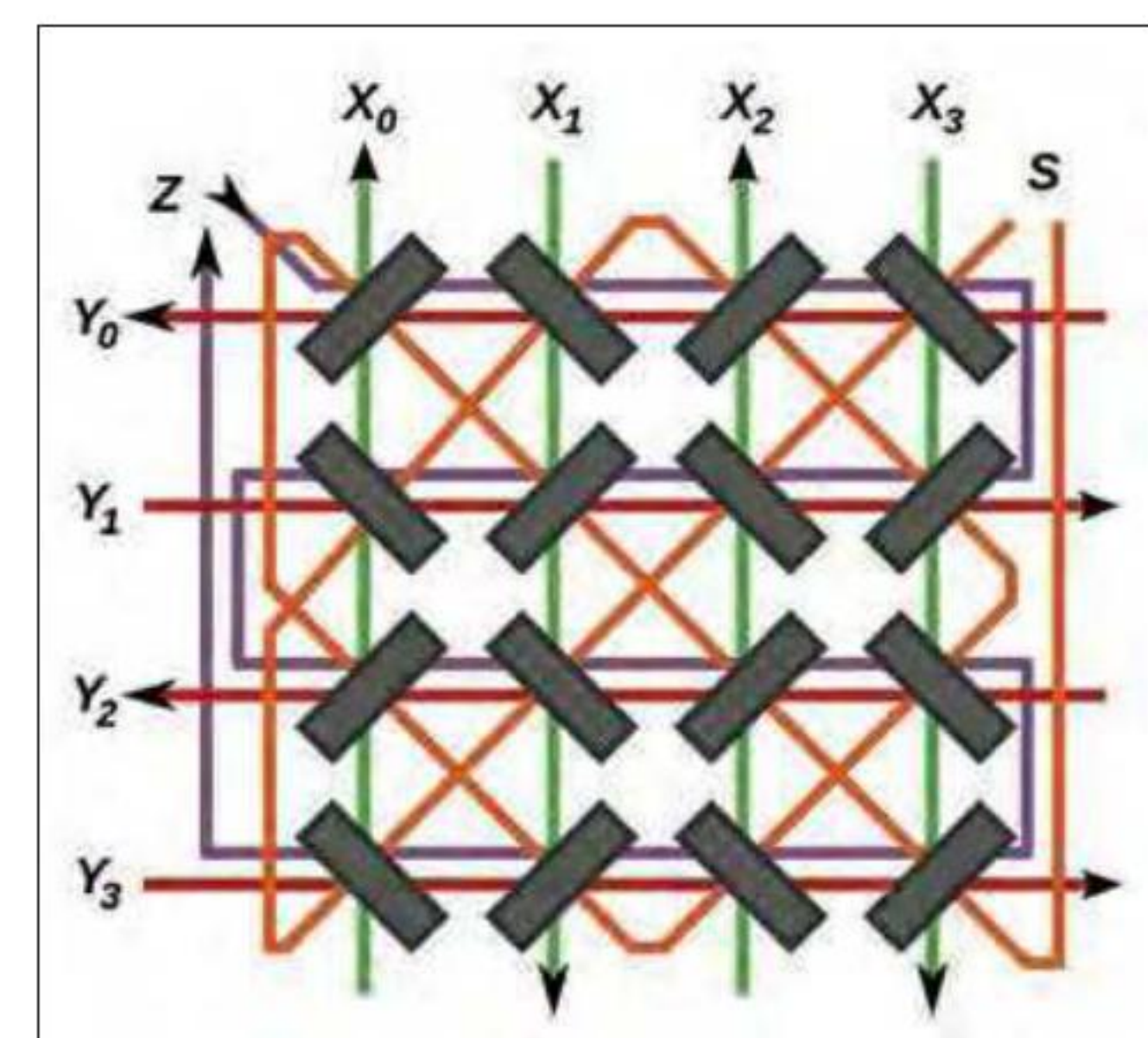


Fig.5. 4x4 magnetic core memory (Source: Tetromino/Wikipedia)

we thread two wires through our core and apply pulses of current through both wires, where the current values in each wire are just a tad over half the value required to magnetise the core. This is the point where Fig.5. starts to make sense. If we send our half-power pulses through wires X1 and Y1, only the core at the intersection of these two wires will be affected.

One thing to note is that Fig.5 represents a $4 \times 4 = 16$ array of 1-bit words. In this context, it's common to call the array a 'plane'. If we wanted to have 8-bit words, then we would replicate this plane eight times (we can visualise these planes as being stacked on top of each other, which was a common way of doing things in the real world).

One advantage of a magnetic core store is that it's non-volatile, which means it retains its data when power is removed from the system. Another advantage is that it's a form of random-access memory (RAM), which means we can randomly access any part of the memory as and when we want to.

One disadvantage of this form of memory is that it we have to write to it in order to read it, resulting in what we call a 'destructive read.' Take our core located at the intersection of wires X1 and Y1, for example. If we want to know whether it contains a 0 or a 1, we would inject current pulses corresponding to a 1 and observe the pulse value coming out on the sense wire (S), which would vary depending on whether the core originally contained a 0 or a 1. Unfortunately, if the original value were a 0, we would have just overwritten it with a 1, which means we would now have to re-write the 0.

Although it may seem a bit 'clunky' now, magnetic core store was the predominant form of RAM for around 20 years between 1955 and 1975. Also, 'clunky' really isn't the right word, because the cores could be teeny-tiny—like 1mm in diameter—with hair-fine insulated wires weaving their way back and forth.

There are several reasons why I'm waffling on about this here. The first is that a couple of days ago as I pen these words, I found myself escorting a friend and his son who were visiting Huntsville to the US Space and Rocket Center here in town (<https://bit.ly/3PXdCcA>). One of the exhibits is the core store memory from the Saturn 5's Launch Vehicle Digital Computer (LVDC), where the Saturn 5 is the rocket that got us to the moon.

Just the next day, by some strange quirk of fate, I ran across an interesting article on IEEE Spectrum about *The Birth of Random Access Memory* (<https://bit.ly/3zj3RyM>). And then, just to add a big dollop of emblematic whipped cream on top of my allegorical cake, I was introduced to the Core64, which is an incredibly tasty interactive core memory



Fig.6. Lixie displays (Source: Connor Nishijima)

electronic kit (<https://bit.ly/3JdGNpH>). Suffice it to say that I really, really want one of these!

What? Analogue? Again?

As I've mentioned on occasion, I'm a digital logic design engineer at heart. I find the wibbly-wobbly nature of analogue electronics in general, and analogue signal processing (ASP) in particular, to be a tad disconcerting. This makes it all the stranger that analogue topics keep on sneaking their way into my *Cool Beans* columns. In *PE* May 2022, for example, we introduced a low-cost, open-source, not-for-profit cutting-edge analogue computer called *The Analog Thing (THAT)* (<https://bit.ly/3vPcm3Z>). Just a month later, in *PE* June 2022, we discussed the days when analogue ruled and digital drooled, the rise of digital, the current resurgence of analogue in the form of analogue machine learning (AML) inference engines, and the Audio Weaver analogue audio design tool.

The reason I feel moved to mention this is that, although a magnetic core store may appear to be a digital beast as seen from the outside world, the electronics used to drive signals into the cores and read data back out again are predominantly analogue in nature. They involve a lot of analogue pulse shaping, amplifying, conditioning, detecting and processing.

Retro display technologies

It's no secret that I am enamored by retro display technologies; also, by modern reincarnations thereof. One such technology is embodied by the Lixie displays (<https://bit.ly/3vtSmDD>) created by Connor Nishijima (Fig.6).

Each Lixie is composed of 10 sheets of acrylic, where each sheet is laser etched with a numeral from 0 to 9. There are two tricolour WS2812 light-emitting diodes (LEDs) under each sheet, allowing you to select the colour of each digit and even use a mix of colours if you wish. These

bodacious beauties are substantial in size (each one is about 60mm wide and 100mm tall) and visible from a great distance.

The style of the font is reminiscent of that used in old Nixie tubes, which isn't surprising because Connor told me that he dismantled an old, non-functioning tube, placed its cathode filaments on a scanner, and used the resulting scans as the basis for his characters. He originally started with single lines, but eventually decided that a dual line rendition was aesthetically more pleasing. I agree.

I'm not sure who invented the original incarnation of these displays deep in the mists of time, but my friend Steve Leibson maintains a website devoted to the HP9825 desktop computer (<https://bit.ly/3JkZs3c>). As part of this site, Steve covers topics like the first digital voltmeters (DVMs) and the birth of test automation (<https://bit.ly/3oE1qSL>). This is where I discovered that an engineer called Andrew Kay formed a company called Non-Linear Systems (NLS) and created the first DVM in 1952.

Reading further, we discover that 'The first NLS DVM also used a new type of digital display based on stacks of edge-lit, engraved Lucite plates. Each stack (representing one digit) consisted of 11 plates arranged so that they recede from the viewer. Ten of the stacked plates have a numeral deeply engraved on it (digits 0 through 9). The eleventh plate has a decimal-point. A small 'grain-of-wheat' incandescent lamp located along the edge of each plate illuminates the associated plate from the edge. If the lamp is lit, its light travels down the plate, which acts as a light pipe. Eventually, the light strikes the plate's engraved character. The deep groove of the engraving interrupts the light as it travels down the Lucite plate and scatters it towards the front of the instrument where an operator sees the engraved numeral light up.' I'm not sure if Andrew invented this form of display himself, but this is the earliest record I've found.

Excuse me while I change

As I mentioned in my previous column (*PE*, September 2022), On Wednesday, 7 September, I will be giving the keynote presentation at the FPGA Forum in Norway (www.fpga-forum.no). The day before, I'll be giving a guest lecture at the Norwegian University of Science and Technology (NTNU) (www.ntnu.edu).

Due to the vagaries of the print publishing world, including concepts like 'shelf life,' the October 2022 issue of *PE* that you are currently reading will start hitting the stores and dropping through subscribers' letter boxes in the UK during the first full week in September.

Thus, remembering that Norway is an hour ahead of the UK, if you find yourself reading this column between 7:00am and 9:00am on Tuesday, 6 September, then – as you read – I will be prancing around on stage presenting. What this means is that (a) we may be linked by cosmic forces beyond the understanding of mortal man and (b) it's your turn to buy the first round of drinks should we ever meet in the flesh.

When giving a presentation, it's important to have an overall 'theme' to provide a framework upon which to hang the talk's topics, otherwise the audience might think I was just waffling on about whatever popped into my mind (as if). In the case of my presentation to the students, my overarching theme is going to be that of 'Change,' including how much things have changed in my own lifetime. I plan on starting with a quote by the Ancient Greek philosopher Heraclitus of Ephesus (535-475 BC), who famously said, 'The only constant in life is change.' However, since I don't wish to appear dogmatic, I'll also reference a philosopher of our own time, Bon Jovi, who informed us in his 2010 song that 'The more things change, the more they stay the same.' (Actually, this sentiment was first coined in 1849 by French writer Jean-Baptiste Alphonse Karr.) I don't know about you, but I think combining these two points of view leaves me reasonably confident that I've covered most eventualities.

One of the aspects of change I'm going to discuss is display technologies. And one of the display types I'm going to discuss is Lixies, along with their precursor technologies. As part of this, I'm going to have a single Lixie sitting on the desk in front of me performing a simple count sequence, commencing at 0, counting up to 9, and returning to 0 to start all over again. Of course, 'simple' is in the eye of the beholder; we're going to have to include at least a few special effects.

Fabulous FX

The term 'special effects' (often abbreviated as SFX, SPFX, F/X, or simply FX)

is typically used to refer to illusions or visual tricks used in the film, television, theatre, video game and simulator industries to simulate the imagined events in a story or virtual world. I feel it's unfair for those folks to commandeer this term and have all the fun, so I often describe the 'twiddly bits' I add to my display code as being special effects (FX) (sue me).

In this case, unusually for me, I decided that subtlety was the order of the day. As a result, I determined to use only two effects when counting up from 0 to 9, and three effects when cycling back from 9 to 0 (Fig.7).

A high-level transition takes place every second. The first option is to perform what I think of as being a 'sharp' transition, which basically means turning the old number off and turning the new number on at the same time, then waiting a second before doing it all again. The second option is a 'fade' effect, in which we gradually fade from the current digit to the new digit. I'm currently employing 30 fade steps spanning a fade time of 800 milliseconds (ms), which means the new value remains steady for 200ms before the next fade commences, but everything is parameterised and therefore easy to change.

Both sharp and fade effects can be used while counting up from 0 to 9 and when cycling back from 9 to 0. In this latter case, I've also decided to provide an additional 'cascade' effect, whereby we hold at 9 for half a second (500ms) and then spend the next 500ms rapidly counting down from 9 to 0.

My plan is to allow my Lixie to perform its magic throughout my presentation. At the end, we'll see how observant the students were (how many different effects they spotted). We're going to commence with Sharp transitions both up and down. After 10 cycles, we'll keep the sharp transitions while counting up and switch to cascade transitions when returning from 9 to 0. Following 10 of these cycles, we'll switch to fade transitions both up and down. Finally, we'll keep the fade transitions while counting up and switch to cascade transitions when returning from 9 to 0. At this point, we'll switch to a new colour (or colours) and do the whole thing again.

We aren't going to go through this code in depth here, but there are a couple of points worth noting. For example, after defining a bunch of parameters, like the total cycle time (1,000ms, aka 1s), the total Fade time (800ms), and the

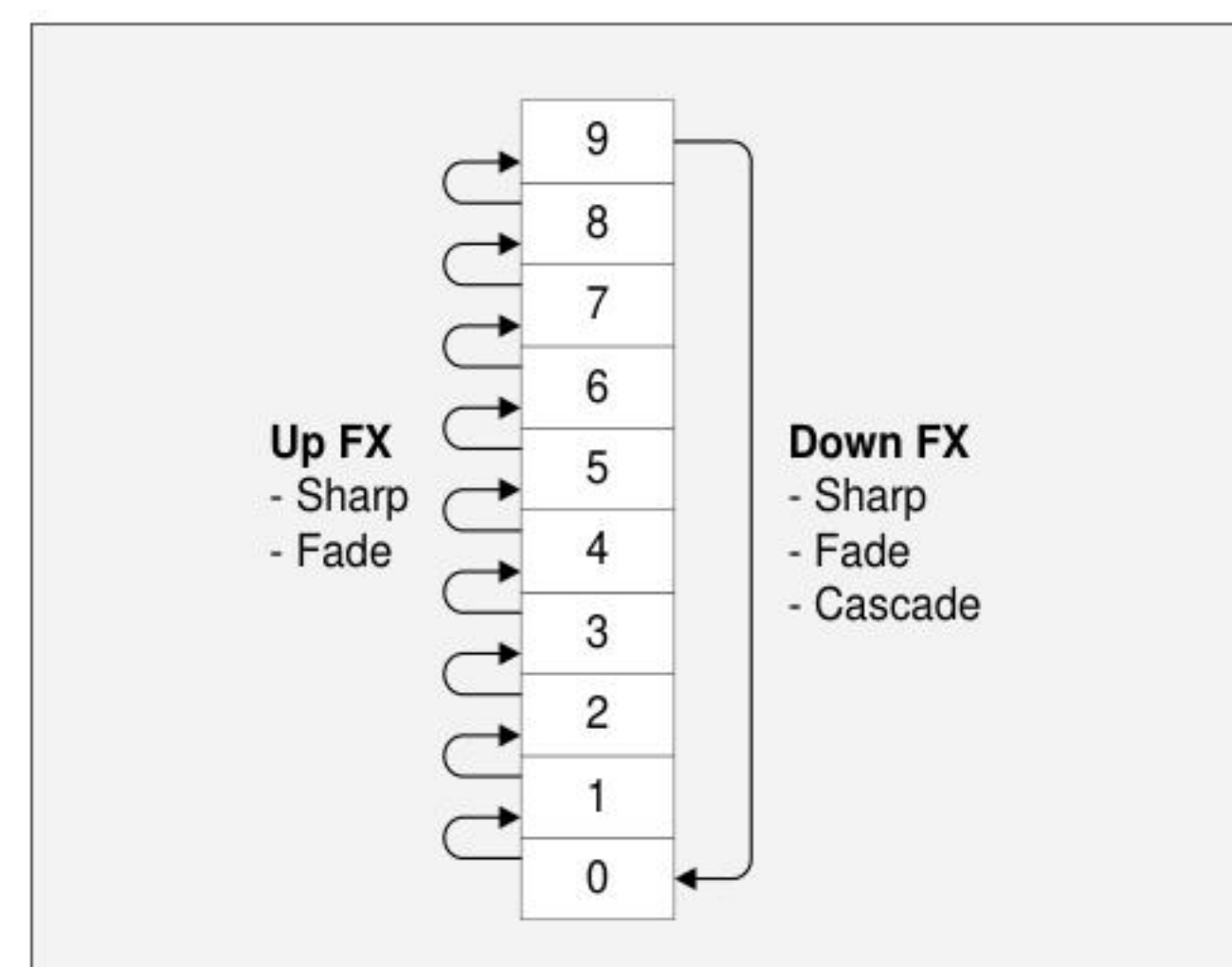


Fig.7. Summary of Lixie effects.

total cascade time (500ms), we use the `typedef` and `enum` keywords to define an enumerated type called `EffectType` that has three members: `SHARP`, `FADE`, and `CASCADE` (enumerations, structures, and type definitions were introduced in *PE*, December 2020). Later, we create a two-dimensional array called `Effects` that groups pairs of effects (the left-hand entry of a pair is the effect to be used while counting from 0 to 9; the right-hand entry when returning from 9 to 0).

```
EffectType Effects[][] =  
{  
    {SHARP, SHARP},  
    {SHARP, CASCADE},  
    {FADE, FADE},  
    {FADE, CASCADE}  
};
```

This program also makes use of some utility functions – `GetRed()`, `GetGreen()`, `GetBlue()`, and `BuildColor()` – along with a `CrossFade()` function that we introduced for use with my 12x12 ping-pong ball array in *PE*, October 2020.

To be honest, remembering that I don't count programming among my skills, I'm jolly happy with my nested control scheme with the counting at the lowest level, selecting a new pair of effects in the middle level, and choosing a new colour combo at the highest level. To achieve all of this we employ the modulo % operator, the use of which we discussed in excruciating detail in *PE*, March 2021. If you wish, you can download the full program (file **CB-Oct22-02.txt**) from the October 2022 page of the *PE* website.

Next time

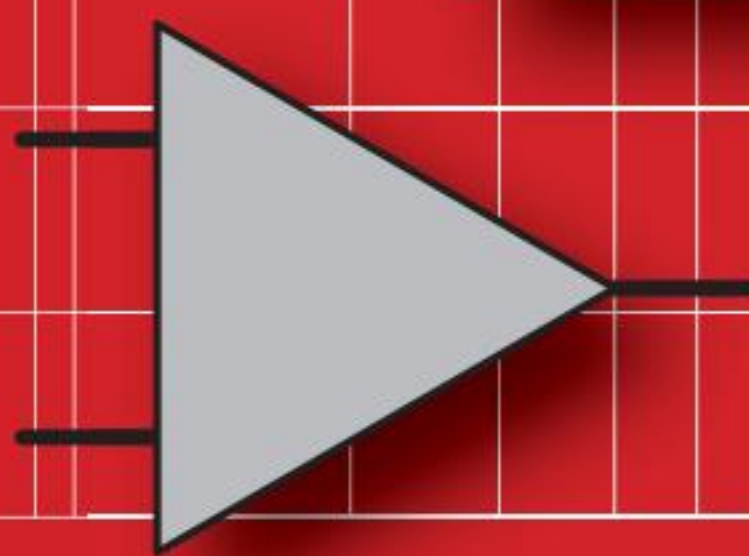
Well, that's all we have time for this month. In my next column we'll... but no! I want this to be as much a surprise for you as it will be for me. Until next time, have a good one!



Cool bean Max Maxfield (Hawaiian shirt, on the right) is emperor of all he surveys at **CliveMaxfield.com** – the go-to site for the latest and greatest in technological geekdom.

Comments or questions? Email Max at: max@CliveMaxfield.com

AUDIO OUT



By Jake Rothman

Transformers in audio – Part 3

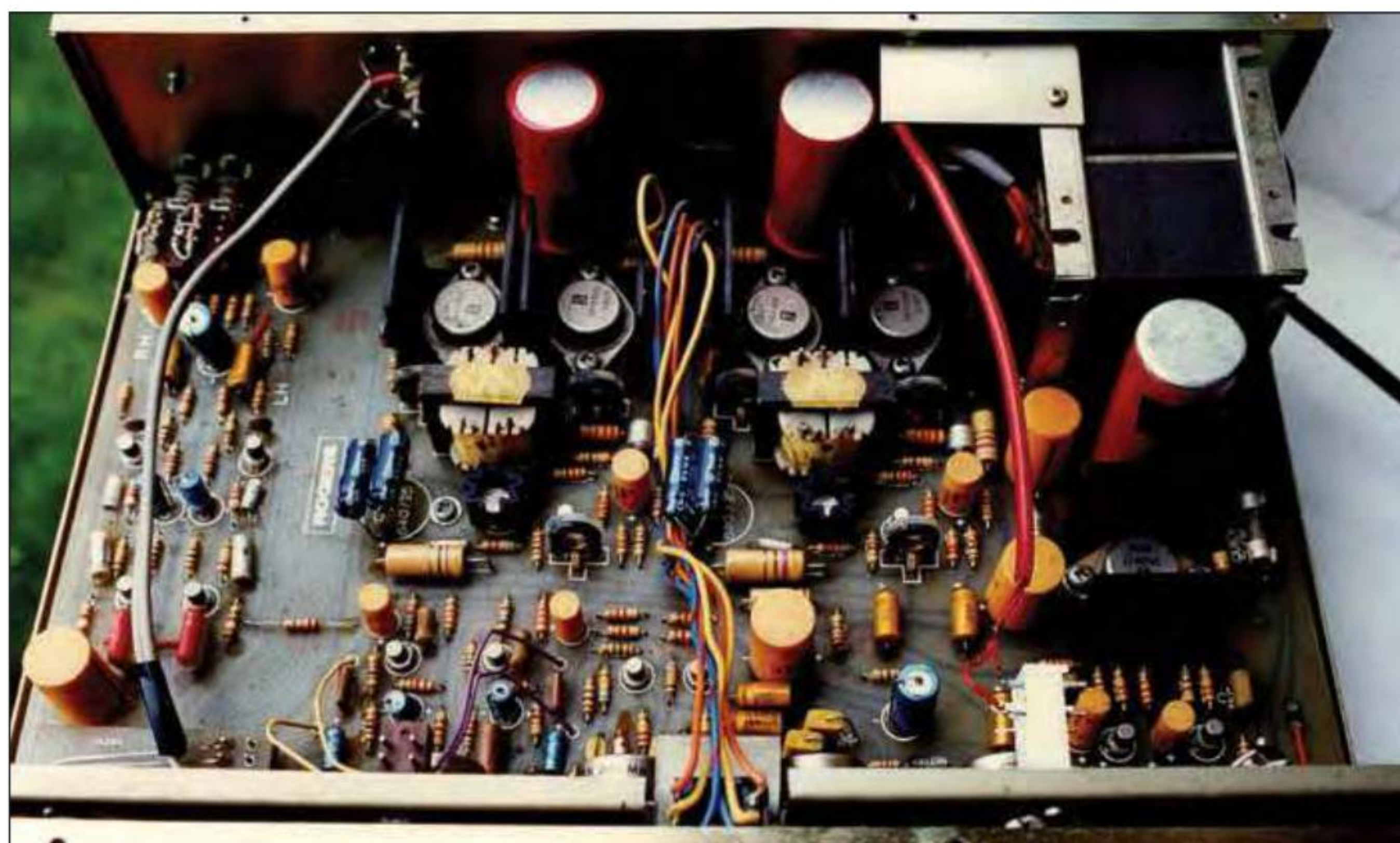


Fig.23. The inside of a 1970 Rogers Ravensbrook amplifier. Note how the cores of the driver transformers (centre) are mounted at right angles to the mains transformer core (top left) to prevent hum pick-up.

In Part 2, last month, we looked at some of the limitations of audio transformers. This month we'll cover techniques manufacturers use to improve performance in real transformers.



Fig.24. PL84 valve guitar practice amp (see Fig.17, *Audio Out*, September 2022). The output transformer used was the B18A011F from Carnhill Transformers.

Loose windings

First though, it seems the level of technical scrutiny is highest in Surrey, and I will pass on details of a few errors that slipped through proofing in recent articles – all reported to me by readers from Surrey!

Fig.6 from *Transformers in Audio – Part 1* (PE, July 2022) shows the Roger's Ravensbrook audio amplifier; note that the phase-splitter transformer allows *output transistors* of the same polarity to be used – *not driver transistors* – as stated in the caption. Also, the unmarked lower preset is 100Ω and the resistor above is 2.2kΩ. This type of circuit is a good introduction to power amp building

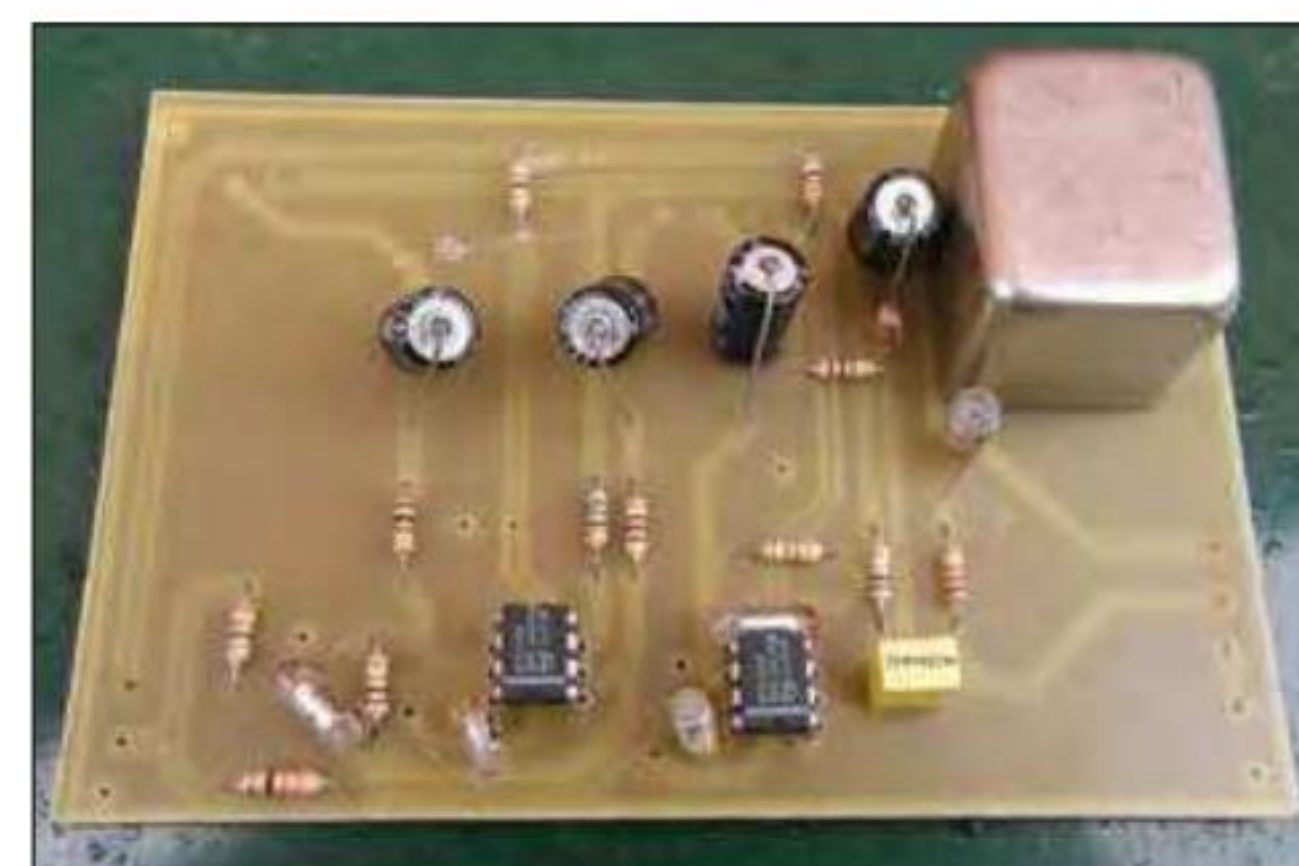


Fig.25. An early prototype of the Steve Dove microphone preamplifier made by Student George Perakis.

because if you make a mistake in the driver stage you don't blow-up your output transistors – the transformer isolates the two sections. The interior of the Ravensbrook is shown in Fig.23.

In *Transformers Part 2* (PE, September 2022), Fig.14a, sharp-eyed reader Peter Brearey has pointed out that the upper output transistor is inadvertently shorted out by a line. This should have taken an 820Ω 1W resistor to the junction of the decoupling network of the 47μF capacitor and unmarked (47Ω) resistor, not the positive rail. It's the same Rogers configuration shown in Fig.6 from Part 1. This circuit prevents current being drawn out of the output stage which would unbalance the quiescent current passing through the output transistors. Also, the speaker impedance of the Mullard Class A amplifier in Fig.18a should be '3Ω', not '3W' and the transformer part number is PT1 (possibly a Partridge design). My apologies for the errata, and the absence of photos for some of the circuits. (Note



Fig.26. Pye Vanguard police radio monitoring unit. Built in 1965, this ran well into the 1980s.

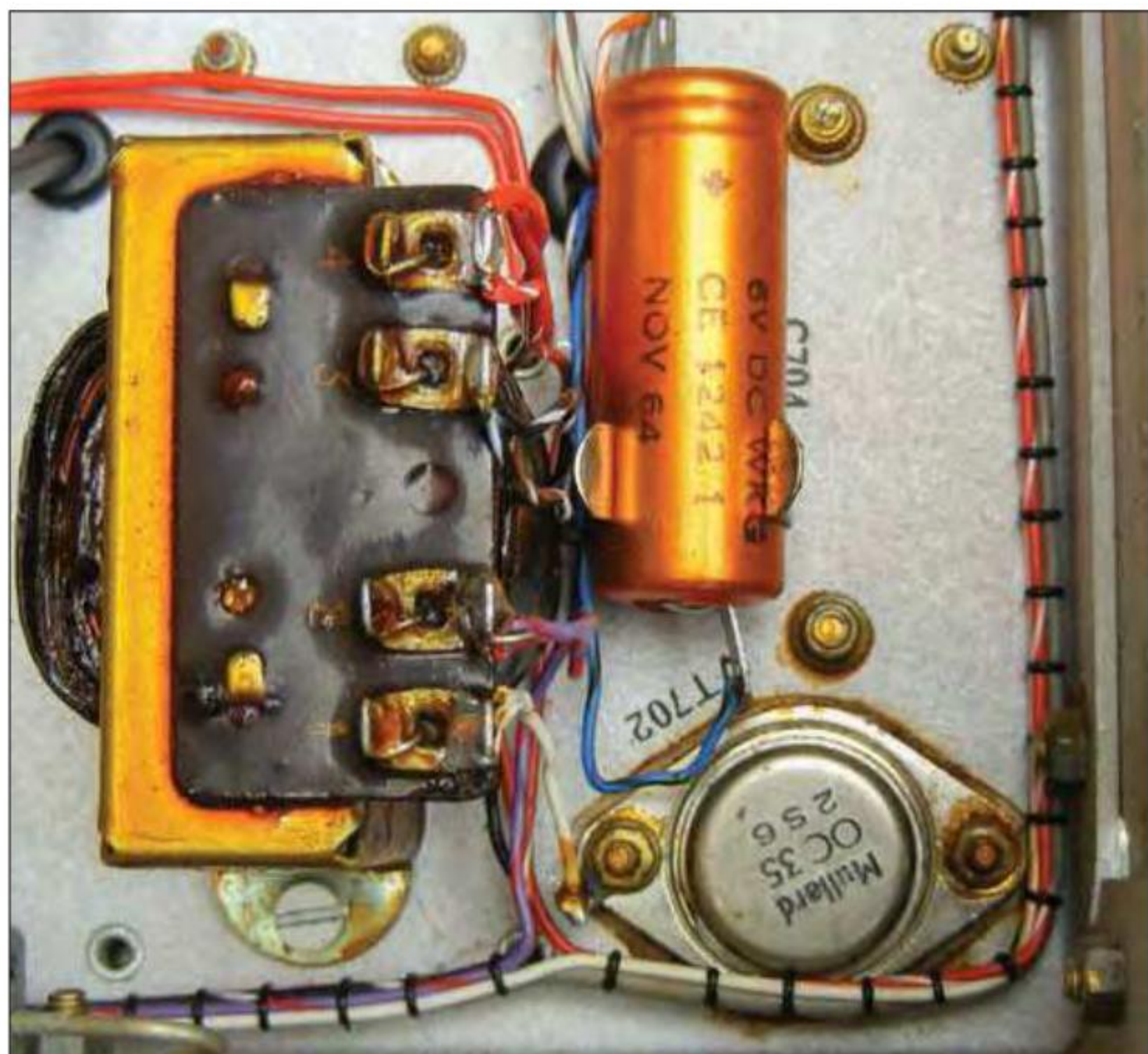


Fig.27. Large, gapped output transformer used in the Vanguard police radio monitoring unit. It delivered a couple of class-A germanium watts into a Celestion 5-inch speaker.

that I do aim to physically build and test all my circuits since paper calculation can only get you in the ballpark with audio design.) Fig.24 shows the PL84 valve amplifier given in Fig.17 and the transformer microphone pre-amp circuit from Fig.20 is shown in Fig.25. Finally, a bit of history, the 1964 Pye Vanguard police radio amp (Fig.19a) is shown in Fig.26 and Fig.27.

Now we'll get back to the special construction techniques used in audio transformers to improve their frequency response and distortion.

Laminations

A good rule of thumb for audio transformers is the thinner the laminations, the lower the losses at high frequencies. This is because the flux tends to concentrate on the surface of the laminations. The result is that audio transformers need to have much thinner laminations than mains transformers which operate

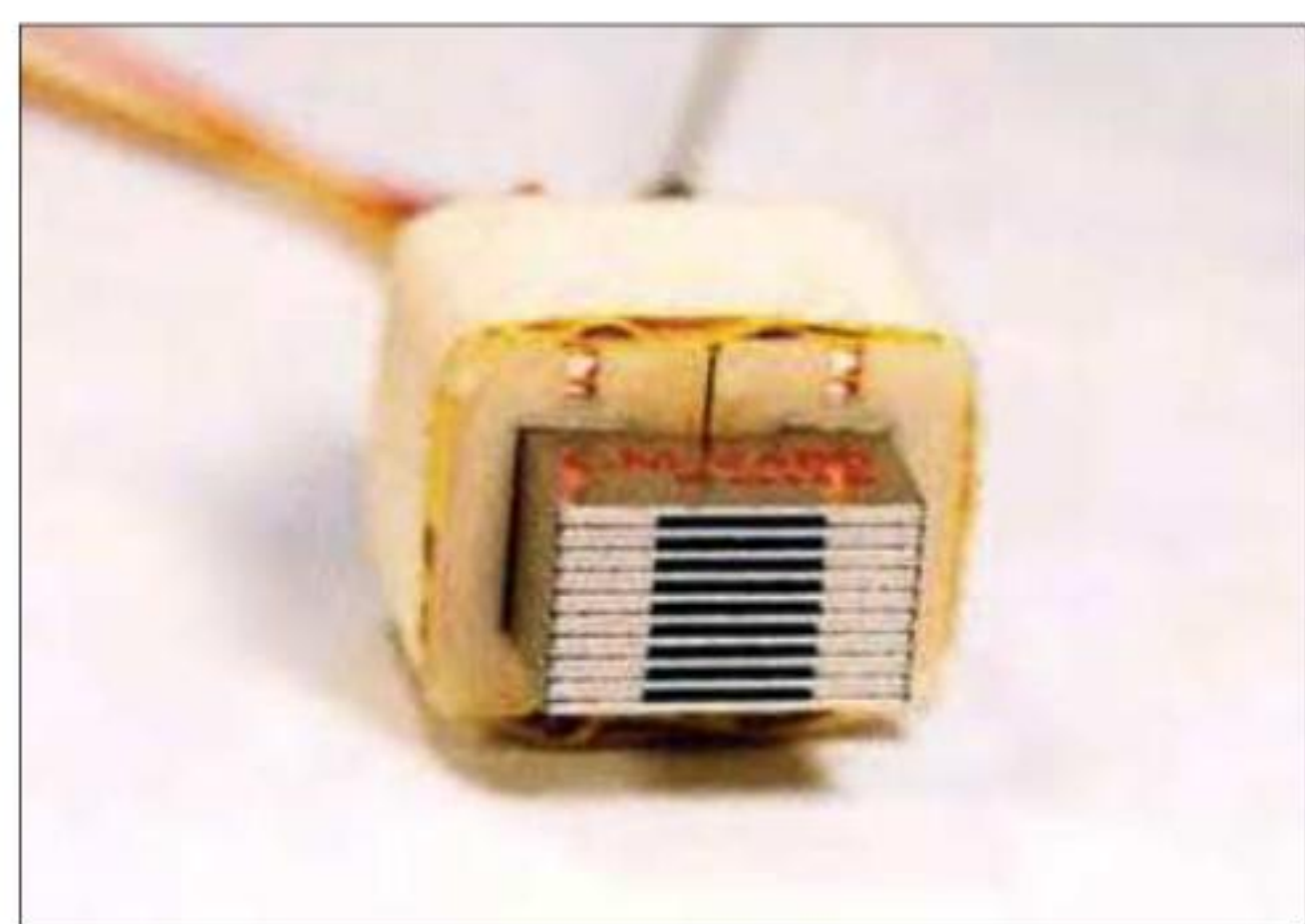


Fig.28. CineMag transformer used in a condenser microphone. It only uses 'U-shaped' laminations. The alternate interleaving gives the misleading impression of a magnetic gap. Notice the twin bobbins/coils.

audio transformers typically have laminations of 0.35mm. Very expensive audio transformers may have laminations just 0.1mm thick. Sometimes imperial sizes are used, typically 15 mils (1 mil = 0.001 inch or 0.0254mm) which is 0.38mm. Audio cores are run at a much lower flux level than power transformers to reduce distortion by avoiding saturation. What matters is obtaining maximum permeability at high frequencies so that inductance is maximised for a given number of turns. This then minimises winding capacitances, extending the response. Mumetal laminations have about 20-times the permeability of standard M6 FeSi transformer steel. However, it can only support about a quarter of the maximum flux density, which means it can only be used for relatively low powers. A common audio approach is to use 49% nickel or 'Radiometal' cores which provide a good compromise between cost, distortion and power handling. This is what is used in most of the medium-cost audio transformers, such as the Vigortronix VTX-A series.

Brian Sowter, who at the fine age of 83 still consults and deals with technical support at Sowters Transformers, told me that the Sowter 5069 transformer used both Mumetal and M6 laminations interleaved. This gives the advantages of both. As the Mumetal saturates, the M6 laminations take over, giving a seamless transition. They used to call it the 'Dolby mix'.

Some small transformers use 'T' and 'U'-shaped laminations and occasionally on some microphone transformers just 'Es' are used. These lamination shapes give higher permeability, but

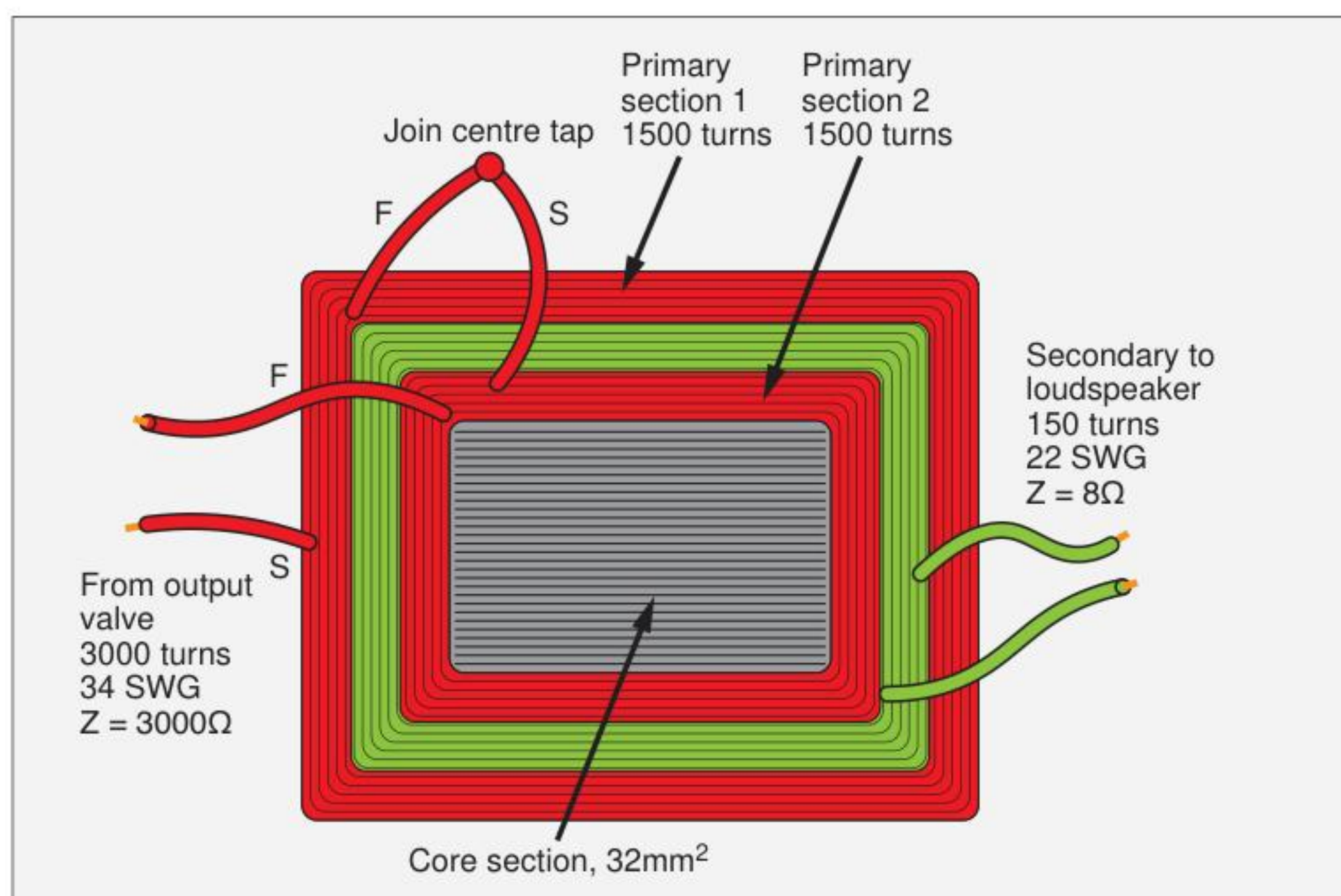


Fig.29. Sectioning of windings improves high-frequency response. This was a simple valve radio output transformer.

at 50Hz or 60Hz. Power transformer laminations are typically around half a millimetre in thickness, while

at the expense of maximum saturation level. This can be seen in the CiniMag microphone transformer in Fig.28. Some microphone transformers have U-shaped laminations with windings either side. This arrangement reduces hum pickup by cancelling out the voltage induced by the hum in the two arms of the core; similar to a hum-bucking guitar pickup.

It is rare for audio transformers to have bolt holes punched in the laminations. These discontinuities in the magnetic circuit can cause flux concentrations and raise distortion. To avoid this, the cores are generally clamped or potted. (Note, however, that low distortion is not necessary for guitar amp transformers, it's part of the guitar's 'sound' or tone.)

Sectionalised windings

If the windings are just two separate coils, such as in a split-bobbin mains transformer, the leakage inductance is high because the magnetic coupling is low. This is one reason mains transformers give very poor high-frequency response when used as audio transformers. An effective technique with valve output transformers is to split the high-impedance primary winding into two layers with the low impedance secondary winding in-between, as shown in Fig.29. This improves the frequency response at 10kHz by around 9dB relative to 1kHz. Fig.30 shows a Sowter 5069 line output transformer with sectioning. This splitting up of primary and secondary windings can be extended to up to 14 sections, as in Sowter's 50W KT88 ultra-linear output transformer for the GEC amp design. This greatly increases the cost, but it does enable response up to 40kHz to be achieved. It is essential to have a wide flat frequency response (with its accompanying low phase shift) if a large amount of negative feedback is used, otherwise oscillation could occur.



Fig.30. If you look down into the bobbin the three sections of this 1:1 ratio Sowter 5069 output transformer can be seen, along with the black screen connection. There is a yellow wire joining the two halves of the outer and inner sections.

Generally, the bigger the turns ratio, physical size and impedance, the worse the high frequency response. It is much more difficult to extend the response of a 20W 8000Ω:4Ω valve output transformer than a 50mW 600Ω:600Ω line-output balancing transformer.

Interlayer insulation

Good insulation is required between the primary and secondary windings in valve output and power transformers – nobody wants +400V HT on their loudspeaker terminals. This is achieved by wrapping polyester tape around each winding. Wax impregnated paper was once used, but it suffered from leakage current and moisture retention, just like old waxed-paper capacitors. Another approach was a special varnish-impregnated glass fibre tape called ‘Empire Cloth’, which was quite good. The Empire name is still around – Empire Tapes make the standard yellow Mylar heat-resisting transformer sticky tape used today (an alternative is

3M type 56). For prototype low-voltage audio transformers, I have used gas-fitters PTFE tape, which is good for pulling everything tight.

Bifilar

Bifilar winding is where two lengths of wire (ie, the transformer’s primary and secondary) are wound on the core together at the same time. The windings thus occupy almost identical magnetic space and have the closest possible magnetic coupling. This technique can be scaled up to trifilar and quadfilar, as in the Ravensbrook and Ravensbourne amplifiers. It is better to buy special multifilar wire ready for such winding – it can be a tricky doing it with two rolls. Driver transformers with centre-tapped or split secondaries are wound this way to avoid switch-off spikes from the output transistors operating in class B. The disadvantage of the bifilar approach is that the inter-winding capacitance is high and the maximum isolation voltage is low.



Fig.31. An old Belclere potted VTX-A-style transformer which I have ‘de-potted’ (so you don’t have to!). Note the soldered joint on the copper screen and the lighter-coloured 49% Nickel (Ni) laminations.

Impregnation

In the old days (from the valve era up to the early 1960s), the varnish insulation on enamelled winding wire was inferior to the more uniform polyurethane coating of today. It was essential to insulate between each layer of the winding with paper, then impregnate the whole lot in wax to render the unit impervious to damp. However, the wax used to melt in service (when running hot) and drip out of the unit. Later, the wax was replaced with polyurethane which was much better... unless you needed to disassemble the transformer for repair.

Sometimes transformers are potted in epoxy resin which minimises microphony, but it’s rigidity can cause lead-out wire breakages and its irreversible solidity makes repair impossible. Impregnants are useful to reduce emitted noise, but they also increase capacitance. I have occasionally heard output transformers ‘singing’ due to loose windings and/or laminations.



Fig.32. This is the amount of fine wire in a Greenweld X7920 interstage transformer. 1770 turns on the primary and 330 turns on the secondary, giving a 5:1 ratio (the measured ratio was somewhat less due to losses). Note the nylon moulded bobbin and laminations.

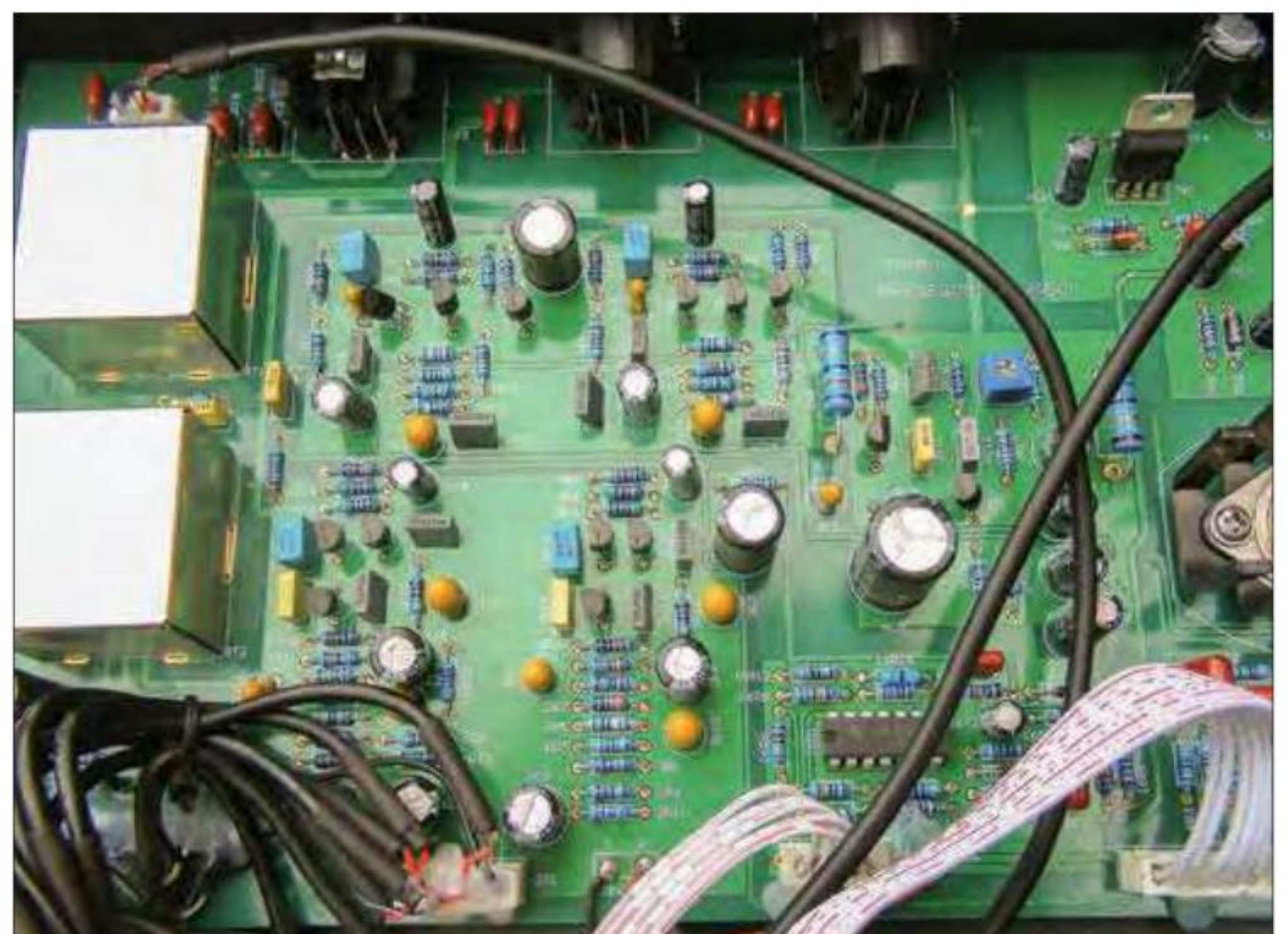


Fig.33. There are many Chinese ‘clones’ of classic British audio products, such as this Neve-copy microphone preamplifier. It suffers from bad hum due to a PCB PSU earth loop and the input transformers having just two steel (not Mumetal) cans which give poor shielding from extraneous magnetic fields.



Fig.34. Screening can for Vigortronix VTX-A transformers. Fitting the transformers can be a challenge, but it's easier with a little silicone grease.



Fig.35. The base plate of a transformer shielding can must be soldered to the transformer's ground pin before it is mounted on the PCB.



Fig.36. The upper part of a transformer shielding can must also be earthed. This can be soldered along the base plate or use a bit of wire from the PCB to the can.

Interwinding screens

Copper foil screens are often placed between windings on input balancing transformers to prevent interference being capacitively coupled; for example, high-frequency switch-mode power supplies buzzing digital audio sources. Care has to be taken to ensure a shorted turn isn't created, the ends of the screen must be insulated from each other by wrapping insulation tape around one end. The screen must be earthed or the interwinding capacitance between the windings is made worse. These screens are often referred to as 'Faraday shields'. Although a screen is not essential on output transformers it is still worthwhile connecting it to earth or chassis if the transformer provides one, especially if it is being driven by something using an un-earthed power supply. Fig.31 shows a Beclere/VTX line-output transformer cut open to show the screen under the primary. This is also connected to the core. (As an aside, since I was in a dismantling mood, Fig.32 shows a Greenweld interstage transformer revealing a mass of fine wire.)

I sometimes connect the shield via a 39Ω resistor to signal ground (if that is the only ground available) to reduce instability in the amplifier driving the transformer caused by the capacitance from the primary to the shield. Normally, the shield is connected to chassis/mains earth and pin 1 on the input or output XLR connector.

A better approach to isolating the shield capacitance from the input driving amplifier is to use an LR network. Jensen sell these, (load isolator, part number JT-OLI-3) – it is simply 40 turns of fine 30 AWG wire wound around the body of a 39Ω, 1W carbon composition resistor (5.5mm x 15mm non-magnetic). This gives an inductance of around 3.7μH. This sometimes isn't enough, so I may use a separate inductor of 10 to 82μH.

Screening cans

Input transformers can easily act like pick-up coils causing hum. Totally enclosing the transformer in a metal can is the solution. Mumetal is the best material (ordinary steel doesn't work very well). There has been a spate of Chinese Neve microphone preamplifier clones, such as the one shown in Fig.33. These suffer badly from hum when mounted in a rack near other equipment because they don't use the correct (pricier) materials needed for effective transformer screening cans – just ordinary steel. Some transformers add a copper 'belly-band' which also reduces hum pick up. Very expensive input transformers will have many layers of screening material.

Optional screening cans (VTX-102-000) are available for the Vigortronix/OEP range, as shown in Fig.34. They are sized 30mm long x 25.5mm wide x 23.75mm high and it's quite a squeeze to insert the transformer – and much harder to remove. A bit of silicon grease is useful, and they should be pushed on gently with a vice along each edge in turn. I

say 'gently', because one must never bend or bash annealed Mumetal because the permeability is reduced. Restoring lost permeability is possible, but difficult for the home constructor – you have to re-anneal it by heating it to 1150°C for four hours, and then cool it down at 250°C per hour.

Note that these cans must be earthed. This is done by soldering the can base to the transformer's screen/core earthing pin (see Fig.35). The upper can must also be soldered to the base plate, as shown in Fig.36 before mounting. Vigortronix supply versions with the cans ready fitted and I usually get these if I need screening, often the VTX-101-003, which is numbered VTX-102-003 when supplied with the can.

Next month

That's all for *Part 3*. Next month, we will conclude with comprehensive information on sourcing audio transformers, plus a very handy pair of PCBs for mounting Vigortronix audio transformers.



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Part 10: Getting to grips with low-power operational amplifiers

Our occasional *KickStart* series aims to show readers how to use readily available low-cost components and devices to solve a wide range of common problems in the shortest possible time. Each of the examples and projects can be completed

in no more than a couple of hours using 'off-the-shelf' parts. As well as briefly explaining the underlying principles and technology used, the series will provide you with a variety of representative solutions and examples along with just

enough information to be able to adapt and extend them for their own use.

This tenth instalment introduces the latest generation of low-power operational amplifiers that can be used with supply voltages of less than 5V.

In recent years, several chip manufacturers have introduced operational amplifiers (aka 'op amps') in single, dual and quad packages designed specifically for low-power and low-voltage operation. Since they can operate with 3.3V and 5V supplies, these devices are ideal for use with modern microcontrollers.

The MCP6400x family of low-power operational amplifiers

A good example of these chips is the MCP6001/4 family of op amps from Microchip. These widely available, inexpensive devices are designed specifically for use in general-purpose, low-power applications, including analogue signal processing circuits and instrumentation amplifiers.

As with many similar devices, the MCP600x family offers a (fairly standard) gain × bandwidth product of 1MHz. However, unlike many earlier devices, they can support rail-to-rail input and output voltage swings, remain stable in the presence of moderate capacitive loads, and operate from supply voltages extending from as little as 1.8V to a maximum of 5.5V. Table 10.1 shows how the MCP600x compares with several other popular types of op amp.

Applications

To give you plenty of food for thought, we have provided you with a handy

collection of sample applications for modern low-power op amps. These circuits have been designed to be as simple as possible to use and all of them will operate successfully with a low-current 5V supply (see later for details of how this can be realised). We will start with the classic fixed-gain inverting amplifier shown in Fig.10.1.

If you are unfamiliar with op amps, the triangular symbol for these devices shows two inputs, one output and two supply connections (positive and ground). Notice that one of the inputs is marked '−' and the other is marked '+'. These polarity markings have nothing to do with the supply connections. Instead, they indicate the overall phase shift between each input and the output. The '+' sign indicates zero phase shift while the '−' sign indicates 180° phase shift. Since 180° phase shift produces an inverted (ie, turned upside down) waveform, the '−' input is often referred to as the 'inverting input'. Similarly, the '+' input is known as the 'non-inverting' input.

The voltage gain of the inverting amplifier is determined by the ratio of R2 to R1. With the values shown, the voltage

gain will be −10. Due to the inverting action, the output waveform will be 180° out of phase with the input (as depicted by the two waveforms shown). The input impedance of the amplifier is nominally 1kΩ (determined by the value chosen for R1). Fig.10.1 can be easily modified for different gains and input resistances by simply changing the resistance values. The lower cut-off (−3dB) frequency (f_1) is determined by the values chosen for C1 and R1 and can be determined from the relationship:

$$f_1 = \frac{1}{2\pi C1 R1} = \frac{0.159}{C1 R1}$$

Here, C1 is in farads and R1 is in ohms. The upper cut-off (−3dB) frequency (f_2) is determined by the gain × band width product for the op amp. With a gain of unity (in the case when R2 = R1), the

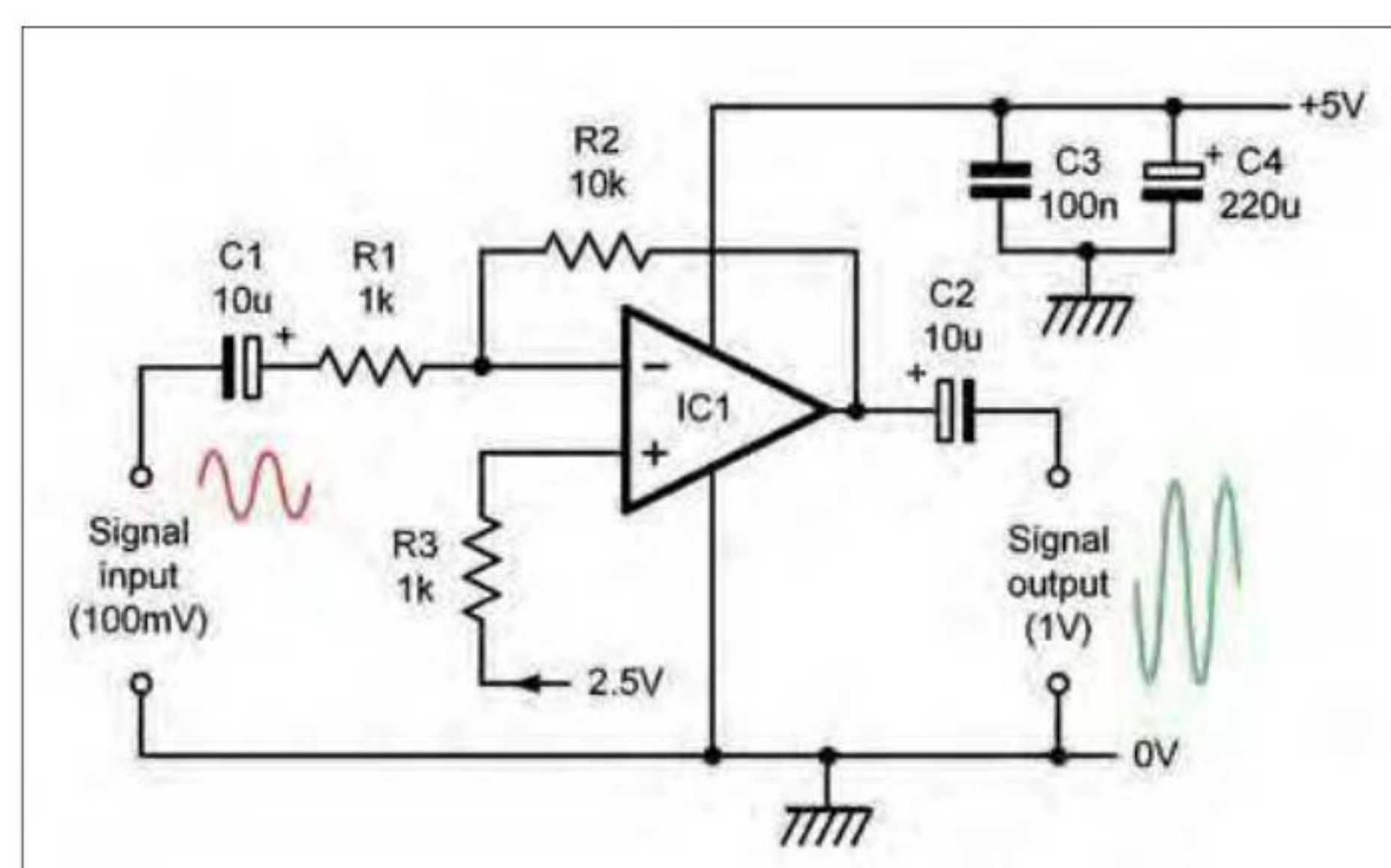


Fig.10.1. Classic fixed-gain inverting amplifier.

Table 10.1 Typical performance comparison of popular operational amplifiers.

Device	Open-loop gain	Gain-bandwidth product	Slew rate	Input resistance	Input offset current	Supply voltage	Supply current
741C	106dB	1MHz	0.5V/μs	2MΩ	20nA	±15V	1.2 to 3.3mA
LM324	100dB	1.2MHz	0.5V/μs	2MΩ	3nA	3 to 32V	1.2 to 3mA
TL081	106dB	4MHz	16V/μs	10 ³ GΩ	5pA	±15V	1.4mA
MCP6001	112dB	1MHz	0.6V/μs	10 ⁴ GΩ	1pA	1.8 to 5.5V	100μA

Table 10.2. Voltage gain and upper cut-off frequency for combinations of R1 and R2 in Fig.10.

R1 (kΩ)	R2 (kΩ)	Voltage gain	Upper cut-off frequency (kHz)
1	10	−10	100
1	22	−22	45
1	47	−47	21
1	100	−100	10
1	220	−220	4.5
1	470	−470	2.1
4.7	47	−10	100
4.7	100	−21	48
4.7	220	−47	21
4.7	470	−100	10
4.7	1000	−210	4.8

upper cut-off will be approximately 1MHz. As the voltage gain increases, the value of f_2 will decrease in proportion, as shown in Table 10.2.

The frequency response of the fixed-gain inverting amplifier is shown in Fig.10.2. The lower and upper cut-off frequencies are approximately 10Hz and 100kHz respectively. Note that the output voltage is shown in decibels (dB) relative to 1V. At the two cut-off frequencies the output voltage will have fallen to 70.7% of its mid-band value (ie, 0.707V for a mid-band output voltage of 1V).

Ensuring stability

To ensure stability (particularly in high-gain applications) the supply to IC1 must be decoupled close to the chip using a relatively low-value capacitor (C3 in Fig.10.1) of typically 10nF to 100nF. An additional larger value decoupling capacitor (C4 in Fig.10.1) should also be fitted but this doesn't have to be placed in very close proximity to the chip. The value of this capacitor should typically be in the range 10μF to 220μF.

Supply arrangements

In common with the other sample applications described in this *KickStart*, the circuit arrangement shown in Fig.10.1 requires a reference voltage supply that's half that of the main supply (ie, 2.5V for a main supply of 5V). This reference supply does not need to deliver any appreciable current and it can be derived from a simple decoupled potential divider like that shown in Fig.10.3(a). For larger applications where several op amps are involved, the arrangement shown in Fig.10.3(b) can be used. This circuit can

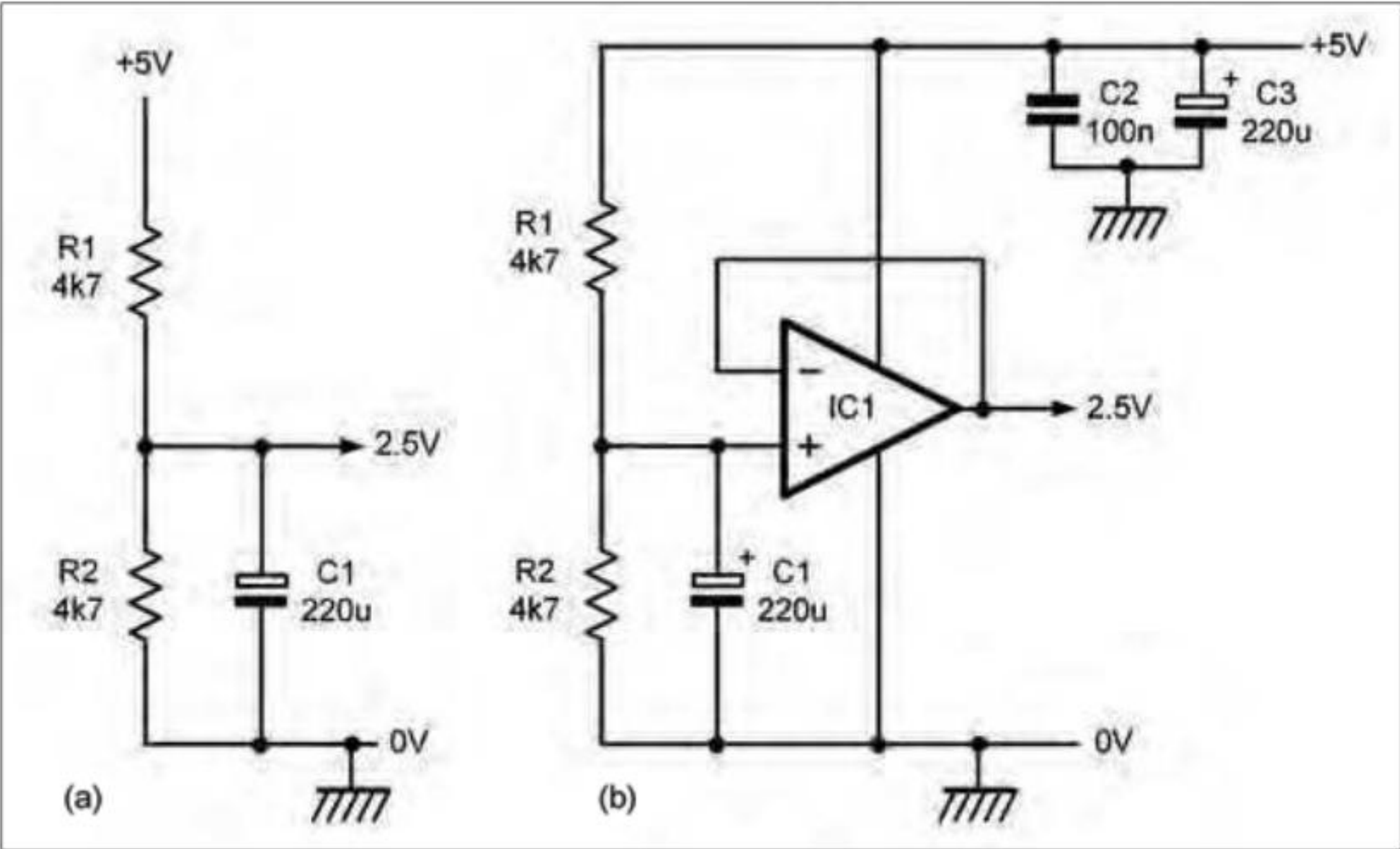


Fig.10.3. 2.5V reference supply arrangements.

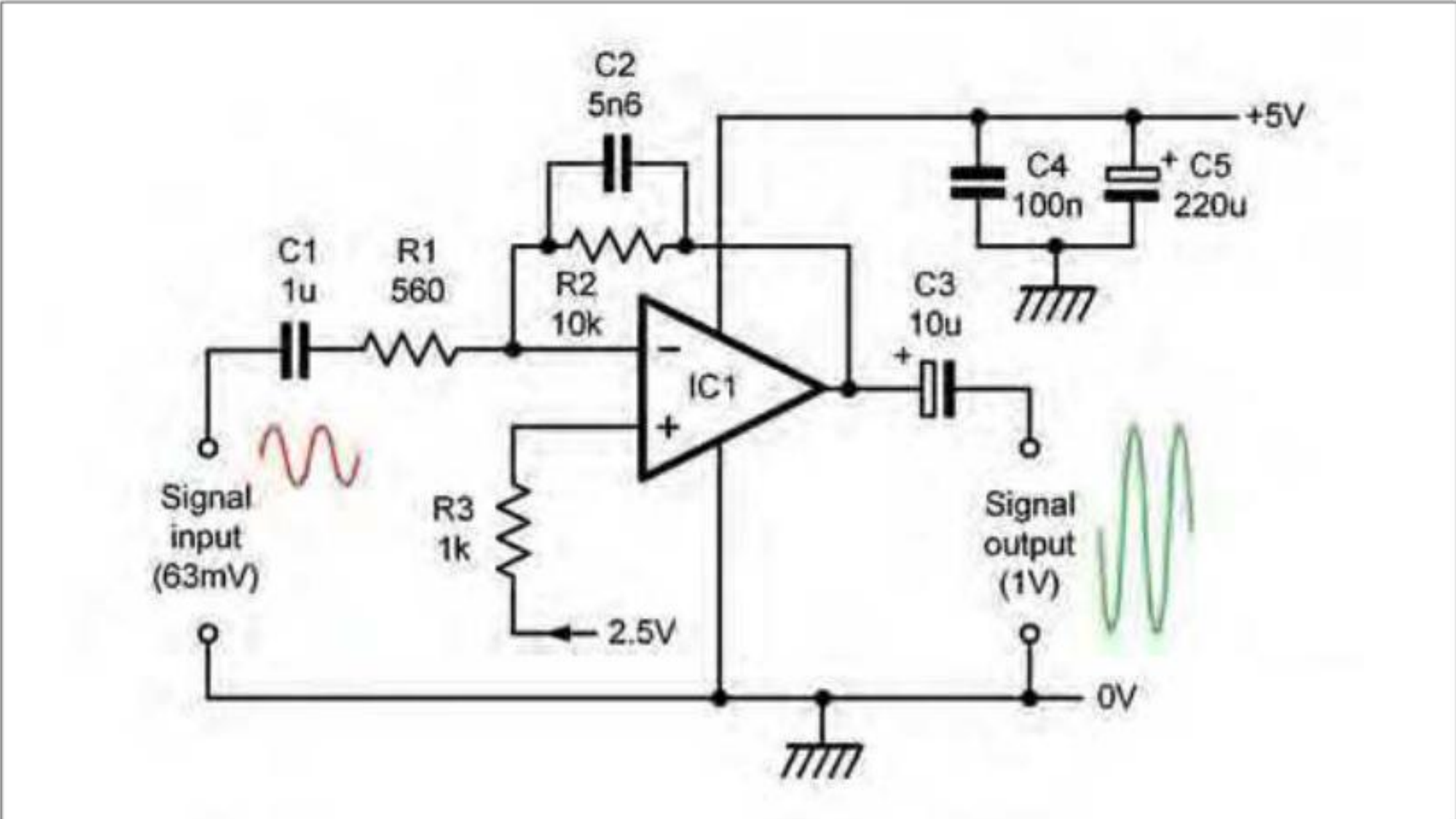


Fig.10.4. Communications microphone op amp preamplifier.

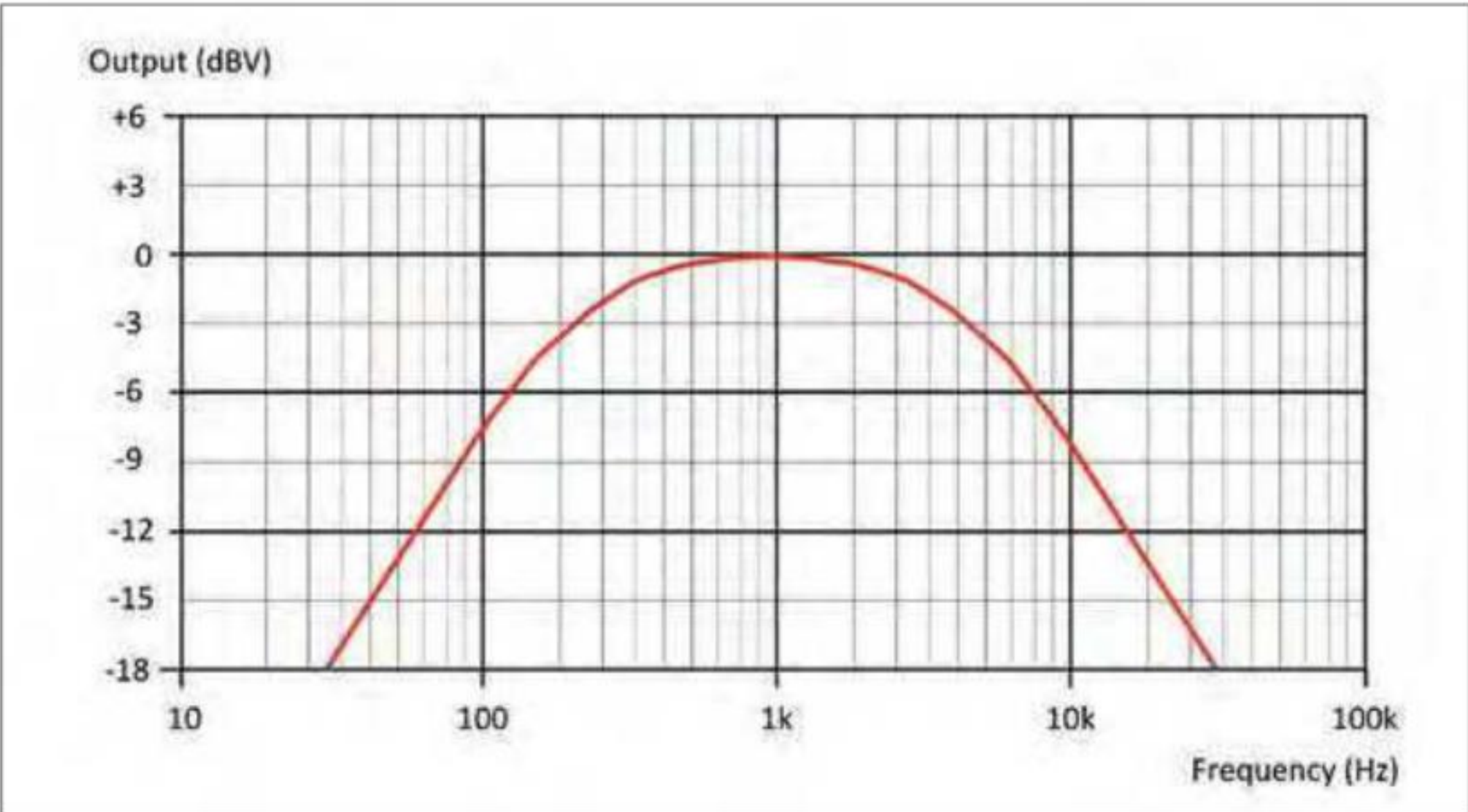


Fig.10.5. Frequency response of the communications microphone op amp preamplifier.

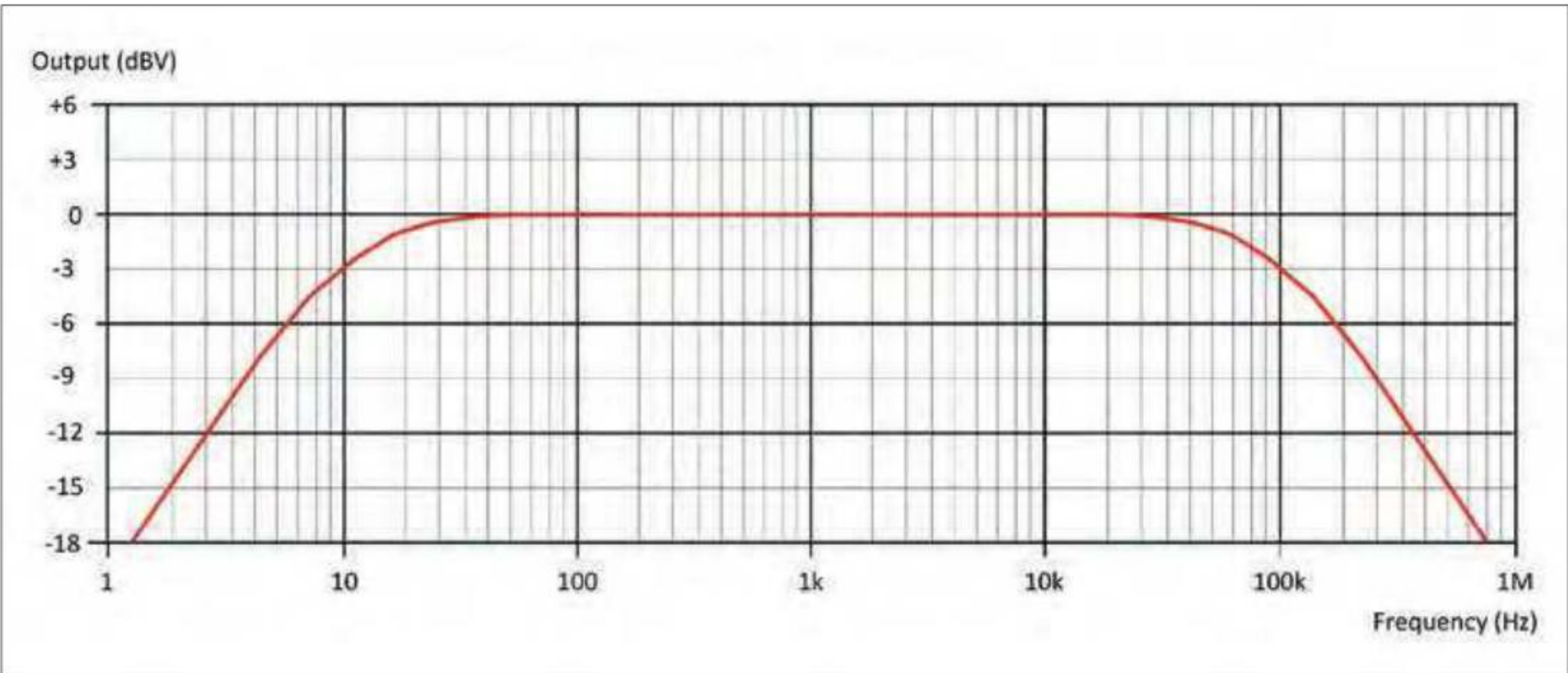


Fig.10.2. Frequency response of the fixed-gain inverting amplifier.

be particularly useful where a 'spare' (ie, unused) op amp is available within a dual (MCP6002) or quad (MCP6004) package.

Microphone preamplifier

Fig.10.4 shows a development of the basic fixed-gain inverting amplifier that we met earlier. This circuit was designed for use as a communications microphone preamplifier to match an impedance of around 600Ω. The circuit provides a nominal output of 1V for an input of 64mV at 1kHz (a voltage gain of 24dB). The lower cut-off frequency is determined by C1 and R1 (as before) while the upper cut-off frequency (f_1) is determined by C2 and R2 using the following relationship:

$$f_1 = \frac{1}{2\pi C_2 R_2} = \frac{0.159}{C_2 R_2}$$

Here, C_2 is in farads and R_2 is in ohms. With the values used in Fig.10.4 the lower and upper cut-off frequencies are approximately 230Hz and 2.8kHz. The measured frequency response of the microphone preamplifier is shown in Fig.10.5.

High-gain non-inverting audio amplifier

Our two previous amplifier circuits were based on an inverting configuration (where the output is in anti-phase with respect to the input). The circuit shown in Fig.10.6 is a non-inverting high-gain amplifier which also has the advantage of having a very high input impedance (determined by the value of R_1). With the values shown, the circuit of Fig.10.6 provides a voltage gain of around 220 and an input impedance of $1M\Omega$. Once again, note that the upper cut-off frequency will be limited by the $1MHz$ gain $\times$ bandwidth product of the chip (and will be around 4.5kHz with the values chosen).

Speaker driver

The non-inverting configuration can also make a simple speaker driver, as shown in Fig.10.7. This circuit has a voltage gain of 1 and an input impedance of $1M\Omega$. The circuit provides enough output for use as a simple audio beeper, but the audio quality is poor and limited to only a few tens of mW (milliwatts) before distortion becomes significant.

Variable gain high-impedance wideband amplifier

Fig.10.8 shows a variable gain high-impedance wideband amplifier. The circuit provides a gain that is variable from 1 to 11 (a maximum gain of 21dB) and a minimum bandwidth of around 75kHz with a lower cut-off frequency of 2Hz. This handy arrangement is ideal for use in a variety of instrumentation applications where a high input impedance is required.

Audio compressor

Fig.10.9 shows a simple audio compressor. For small signal inputs the circuit exhibits a gain of approximately 18 and the compression action starts when the input voltage exceeds about $100mV_{RMS}$. Beyond this point the voltage gain falls dramatically as the anti-parallel diodes, D_1 and D_2 begin to conduct. The maximum output of the circuit is approximately $0.7V_{RMS}$ and its transfer characteristic is shown in Fig.10.10.

Sinewave oscillator

A sinewave oscillator is shown in Fig.10.11. The frequency of operation (f) is determined by C_1 , R_3 and C_2 , R_4 , given by:

$$f_1 = \frac{1}{2\pi CR} = \frac{0.159}{CR}$$

Here, $C = C_1 = C_2$ (expressed in farads) and $R = R_3 = R_4$ (expressed in ohms).

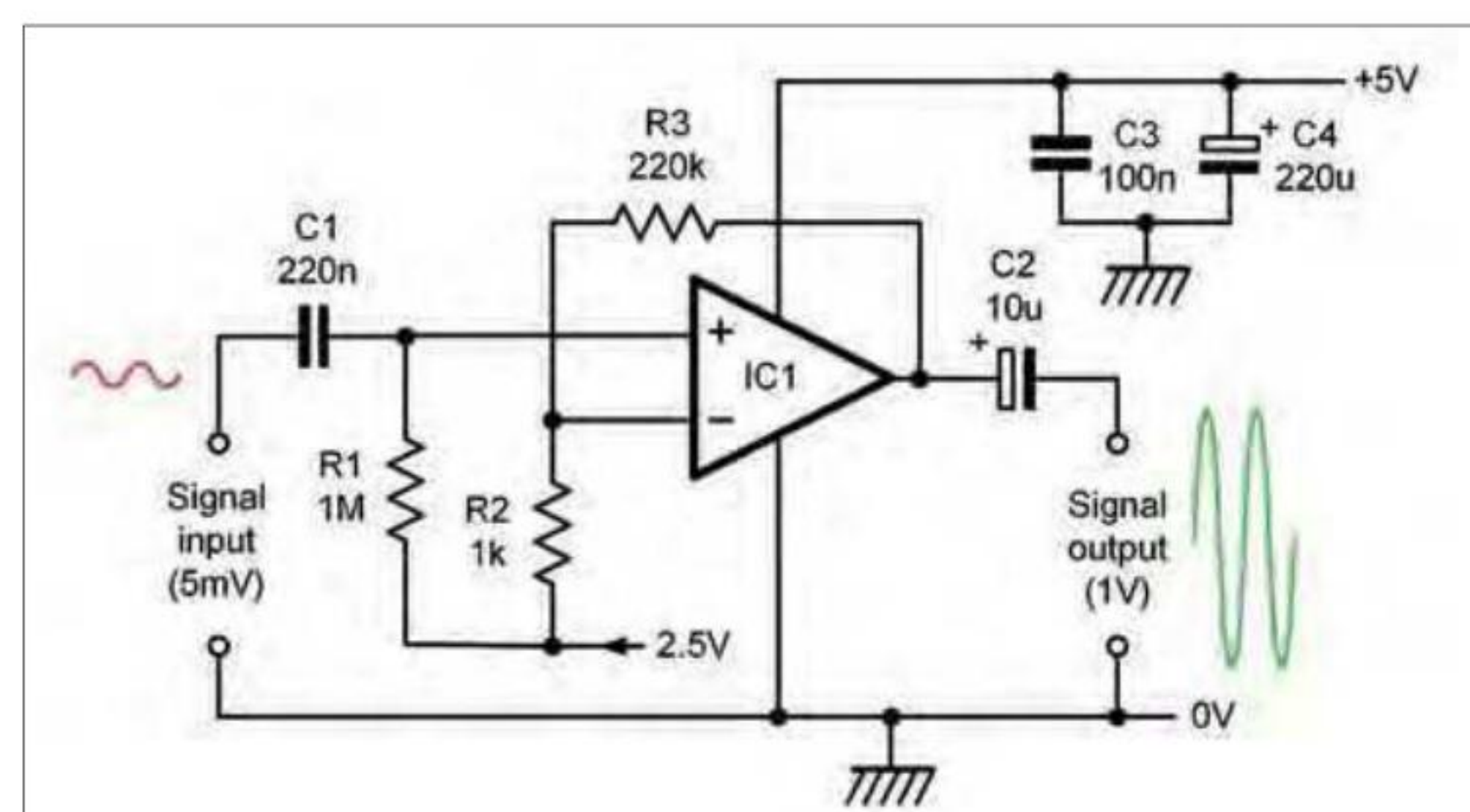


Fig.10.6. High-gain non-inverting audio amplifier.

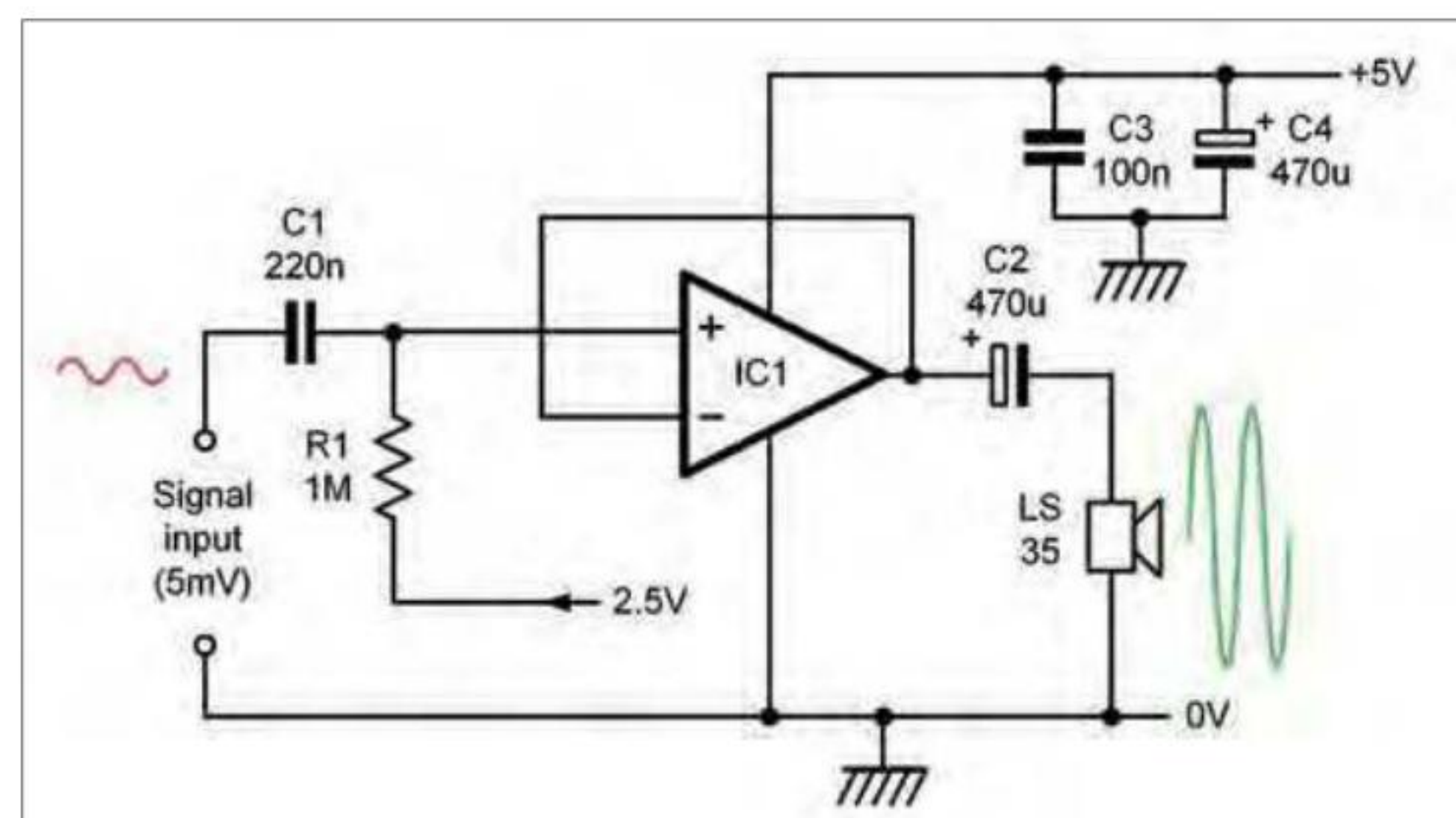


Fig.10.7. Simple speaker driver.

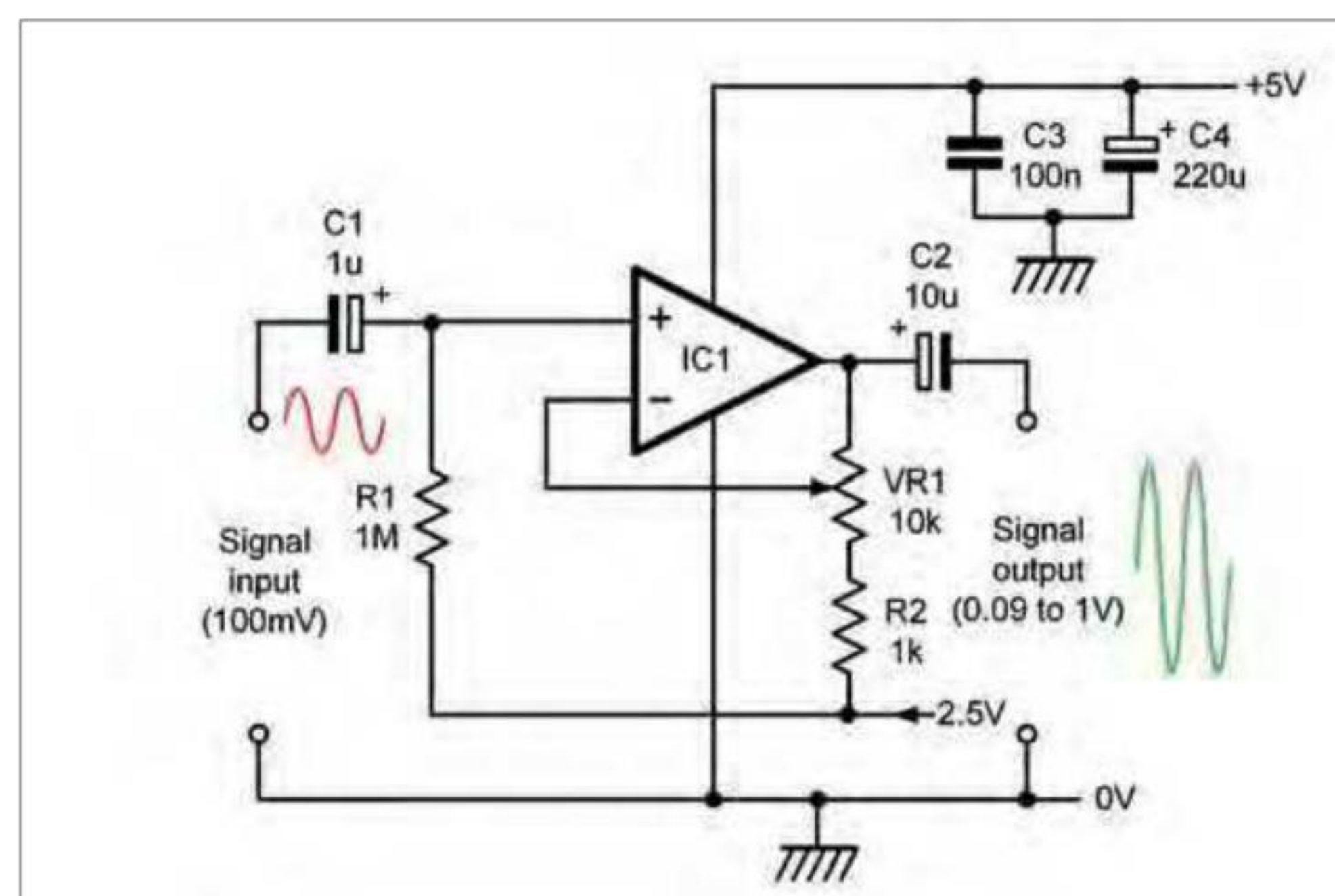


Fig.10.8. Variable gain high-impedance wideband amplifier.

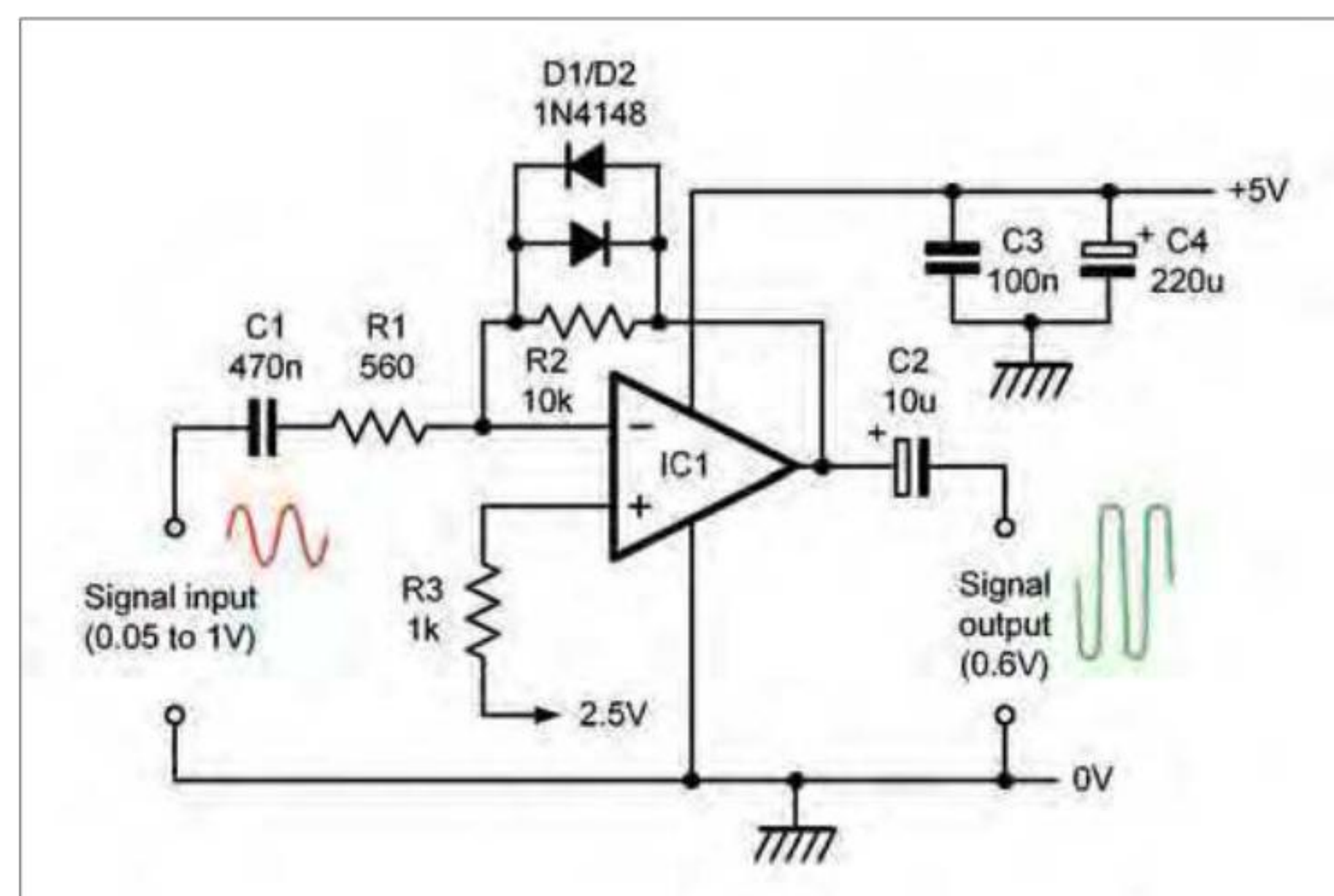


Fig.10.9. Audio compressor.

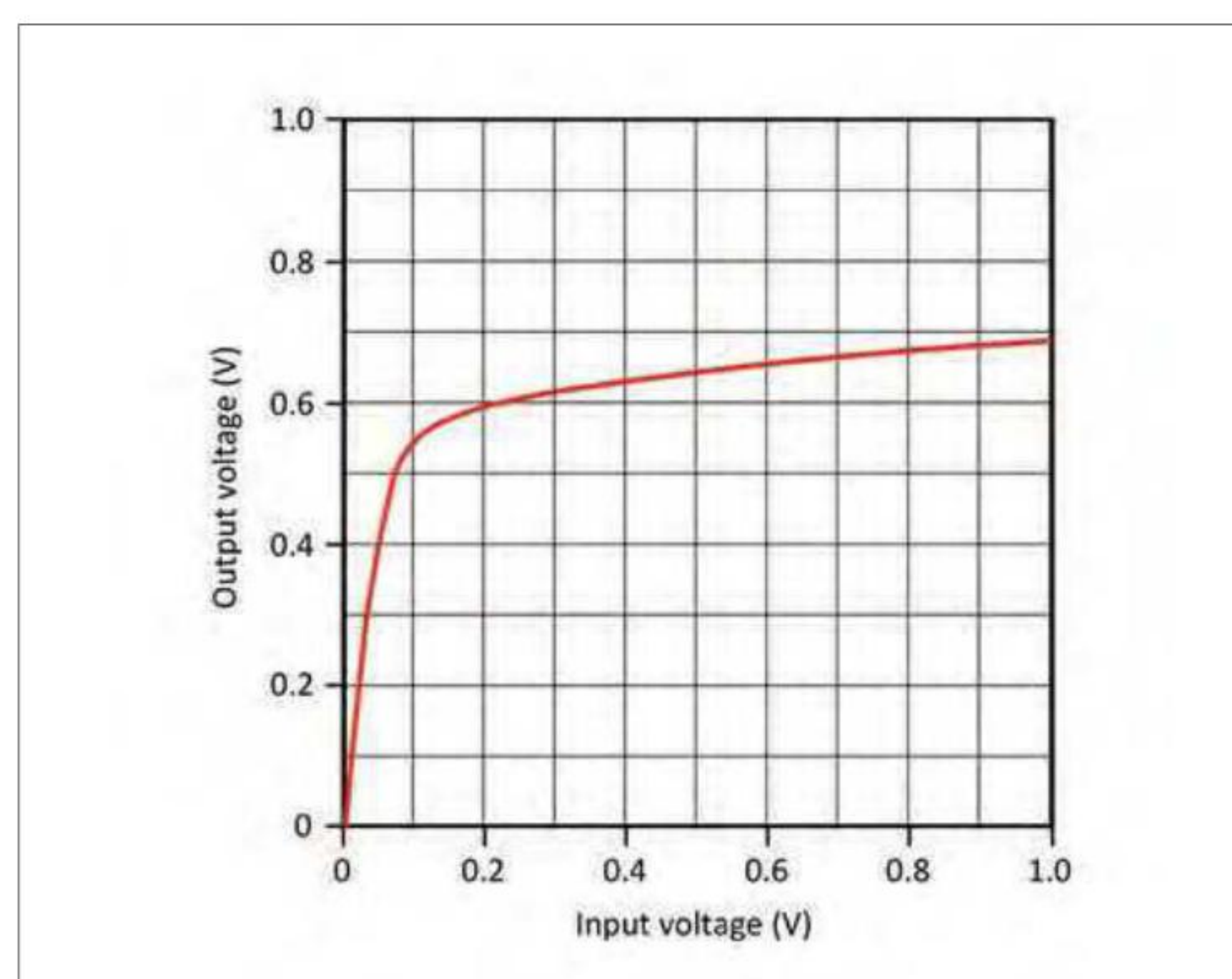


Fig.10.10. Audio compressor response.

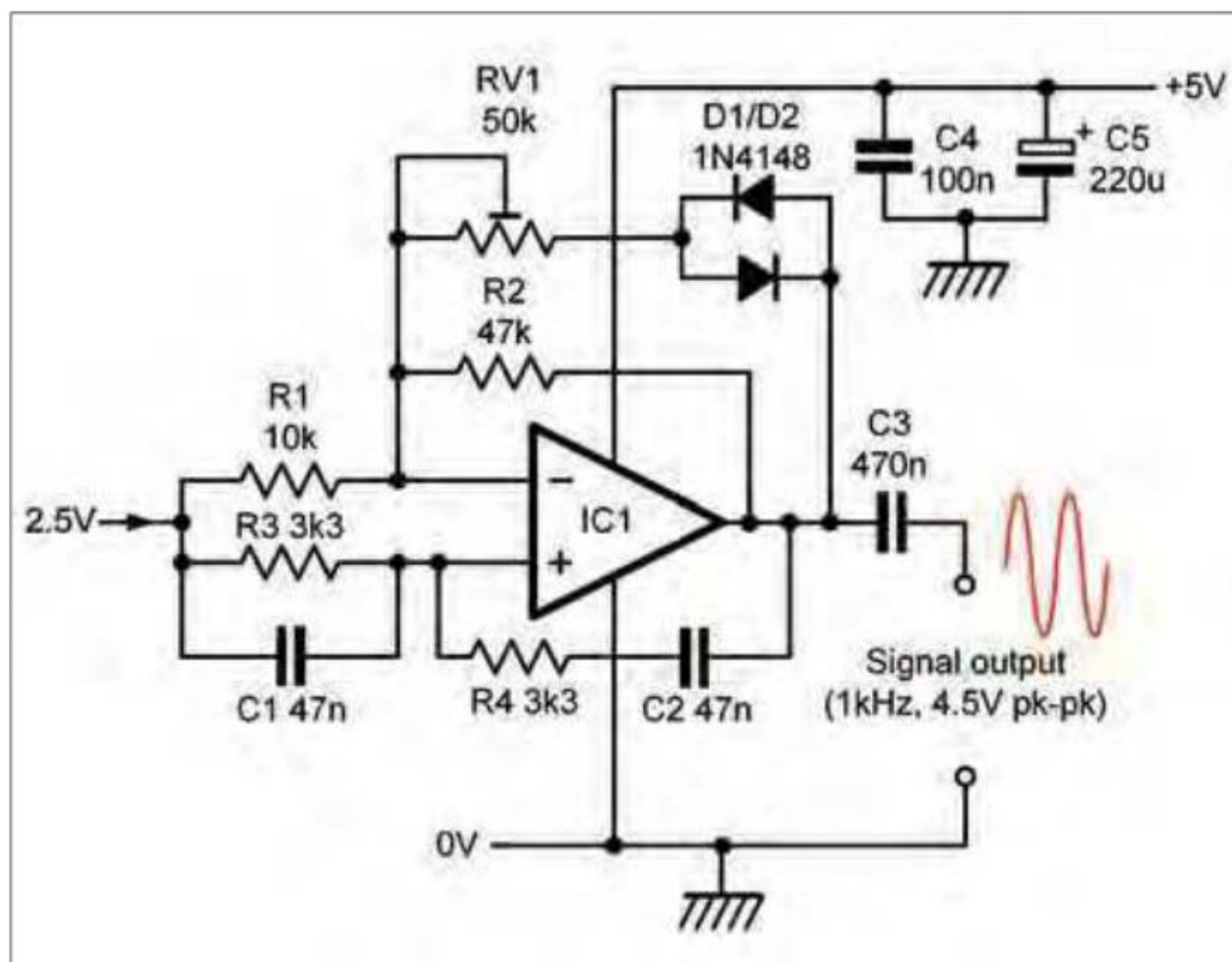


Fig.10.11. Sinewave oscillator.

Using the values shown, the output frequency is approximately 1kHz and the output amplitude is 4.5V_{pk-pk}. RV1 should be adjusted for minimum distortion. Note that although the output is reasonably sinusoidal there will be some distortion present. More sophisticated arrangements dispense with the anti-parallel diodes (D1 and D2) and employ a thermistor to regulate the gain and reduce distortion.

Precision AC-to-DC converter

Precision AC-to-DC conversion (rectification) is another useful application for a low-power op amp. The circuit of Fig.10.12 uses a dual operational-amplifier (MCP6002) and will convert a 0 to 1V_{RMS} AC signal to a corresponding 0 to 1V DC output. The circuit operates well over the entire audio frequency range and its response is extremely linear.

Peak-level meter

Another interesting application of a dual low-power operational amplifier is the audio peak-level meter shown in Fig.10.13. This circuit is ideal for use in a wide range of audio and recording applications. C2 and R2 set the time constant (2.2s) of the circuit. If a faster decay is required, the value of either C2 or R2 (or both) should be reduced. Alternatively, the peak hold time can be increased by increasing the value of one or both of these components.

Audio mixer

Our final application is a simple four-channel mixer shown in Fig.10.14. IC1 is configured as a unity-gain inverting amplifier and the four input voltages are summed together at the inverting input of IC1. The input impedance is nominally 10kΩ for each of the four channels. If necessary, the value of R5 can be increased to provide some gain. For example, values of 220kΩ or 470kΩ will result in gains of 2.2 or 4.7 respectively.

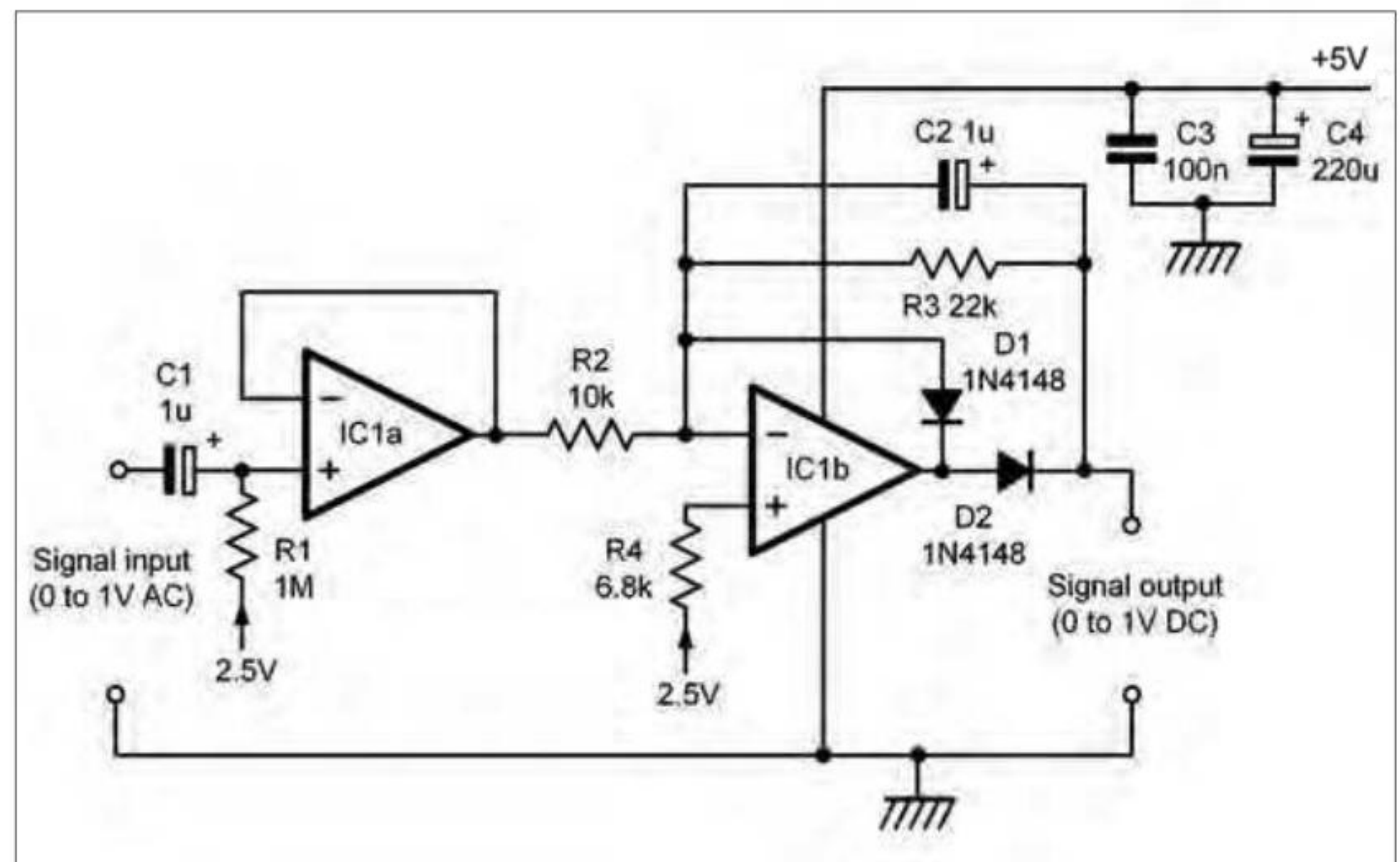


Fig.10.12. Precision AC-to-DC converter.

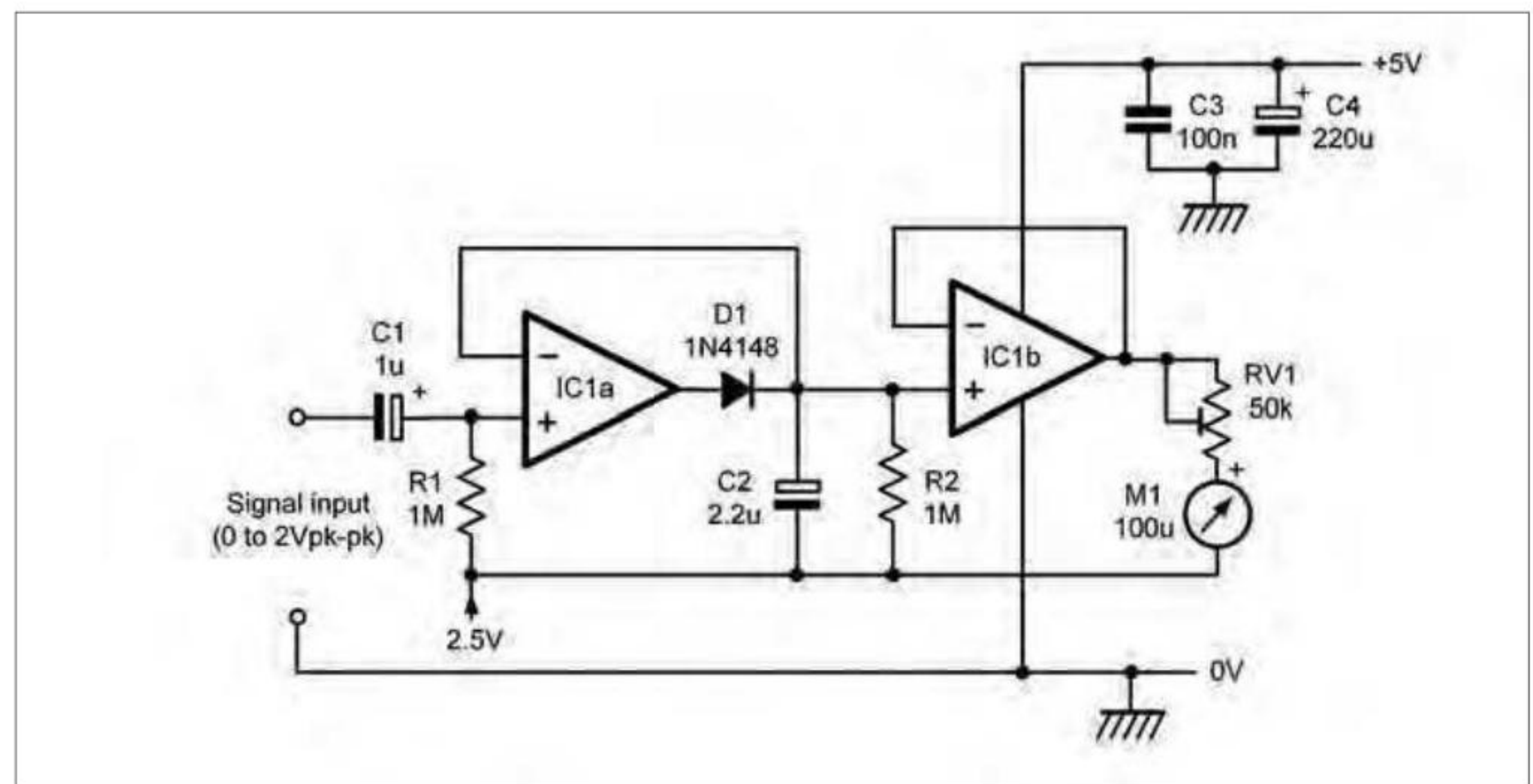


Fig.10.13. Peak level meter.

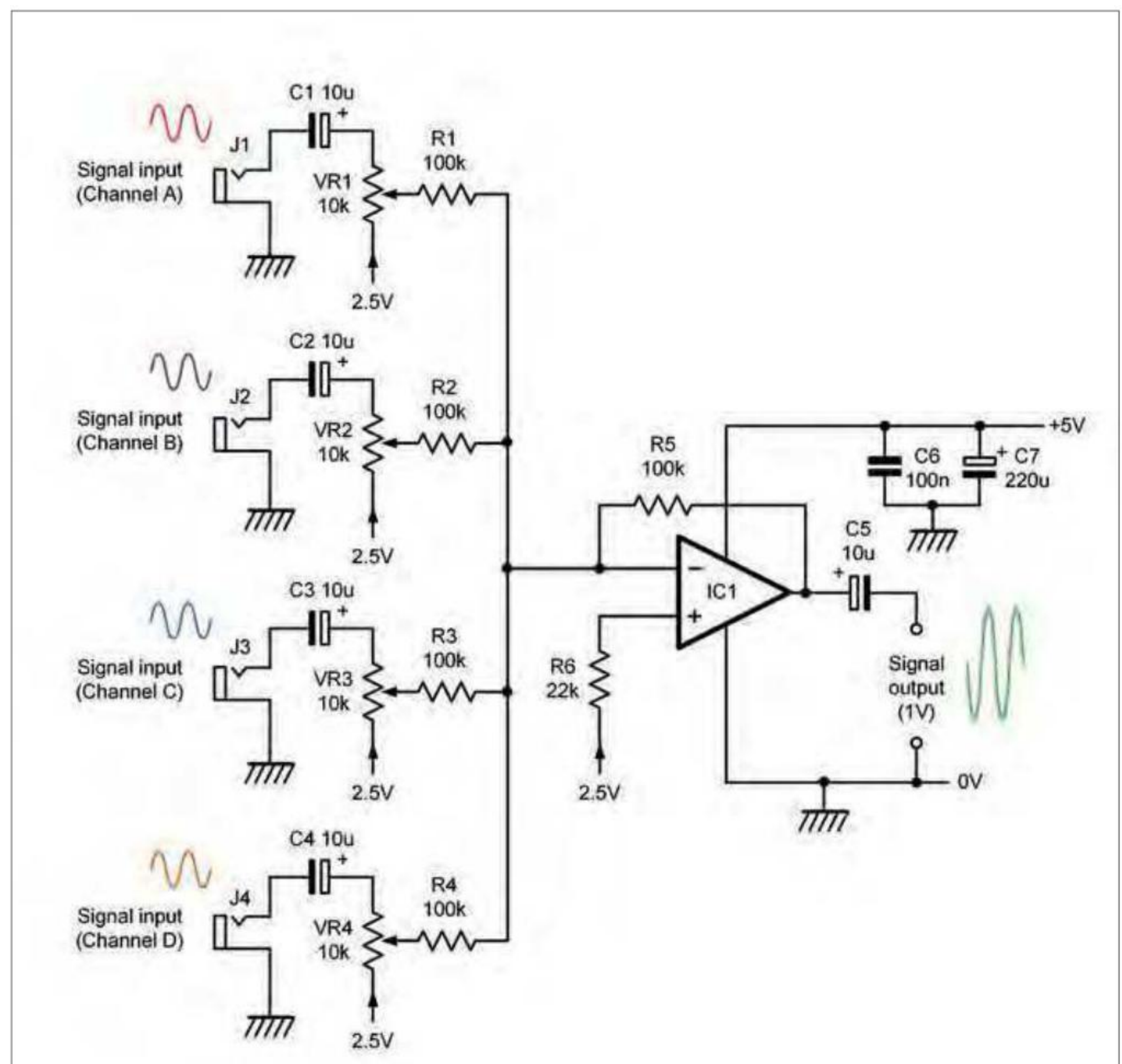


Fig.10.14. Audio mixer.

The MCP600x family

The MCP600x family is supplied in a variety of different package styles,

including SOT, SOIC and PDIP packs, as shown in Fig.10.15. The plastic packaged dual-in-line versions of the MCP6002 and

MCP6004 devices will be adequate for most purposes and easiest to use.

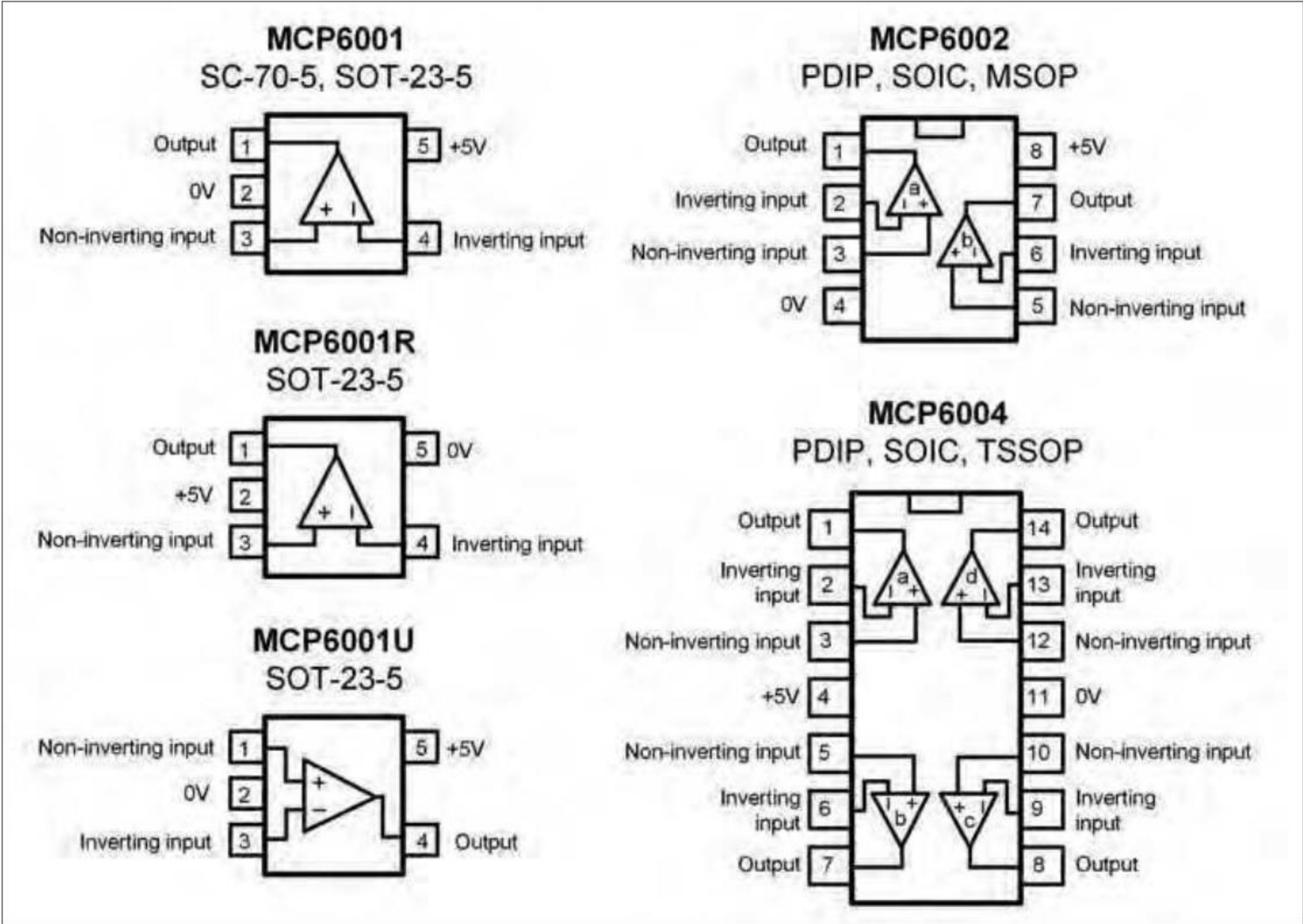


Fig.10.15. MCP6001/2/4 pinouts.

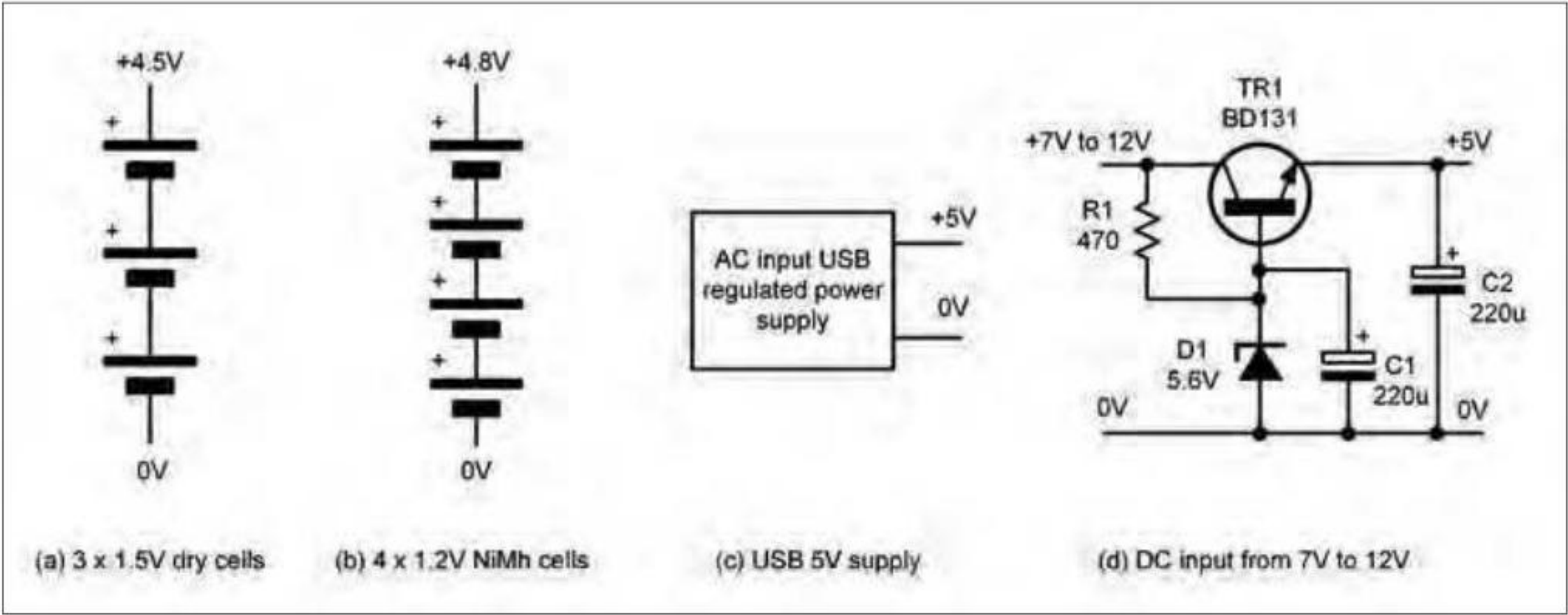


Fig.10.16. Typical power supply arrangements.

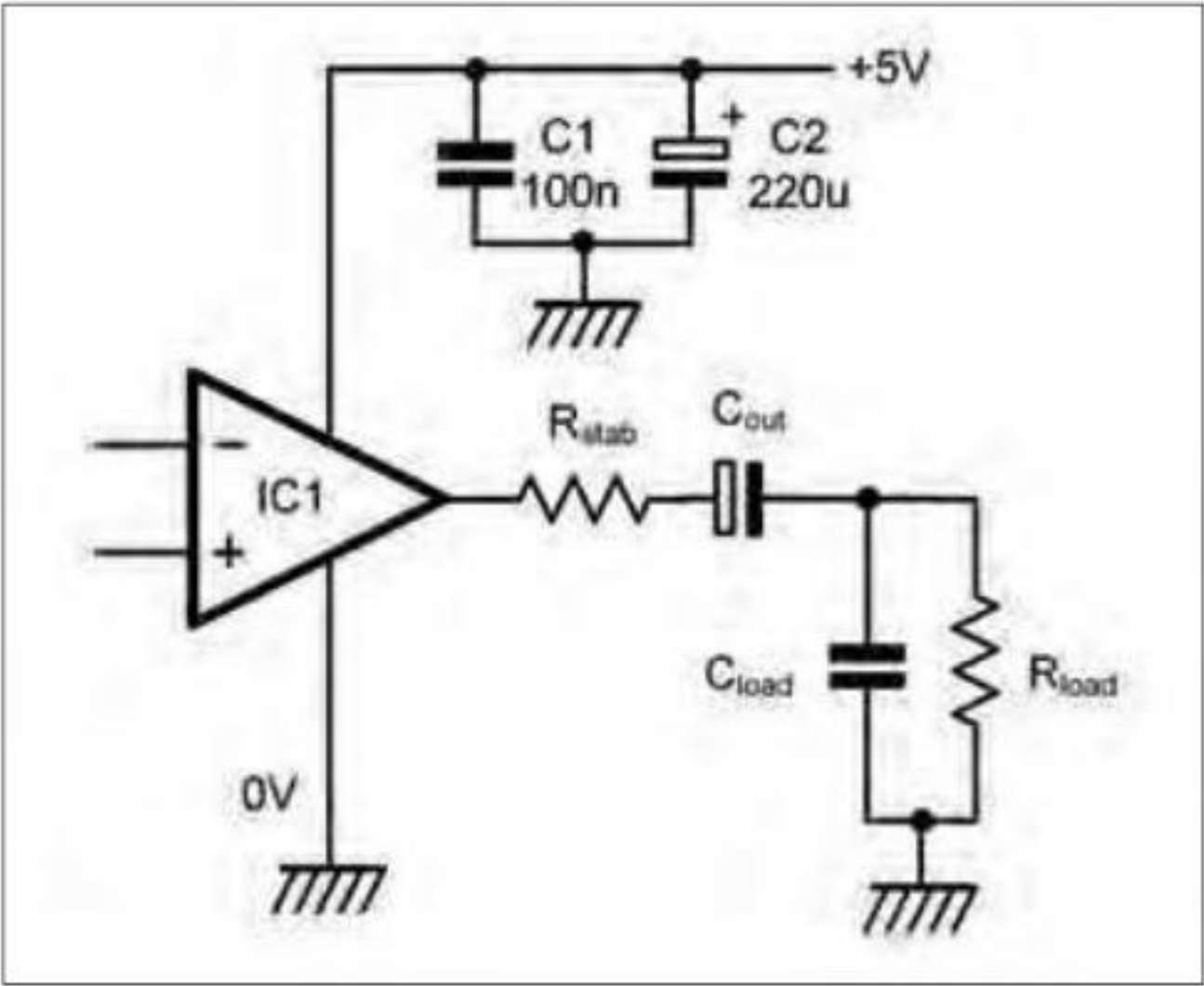


Fig.10.17. Improving stability.

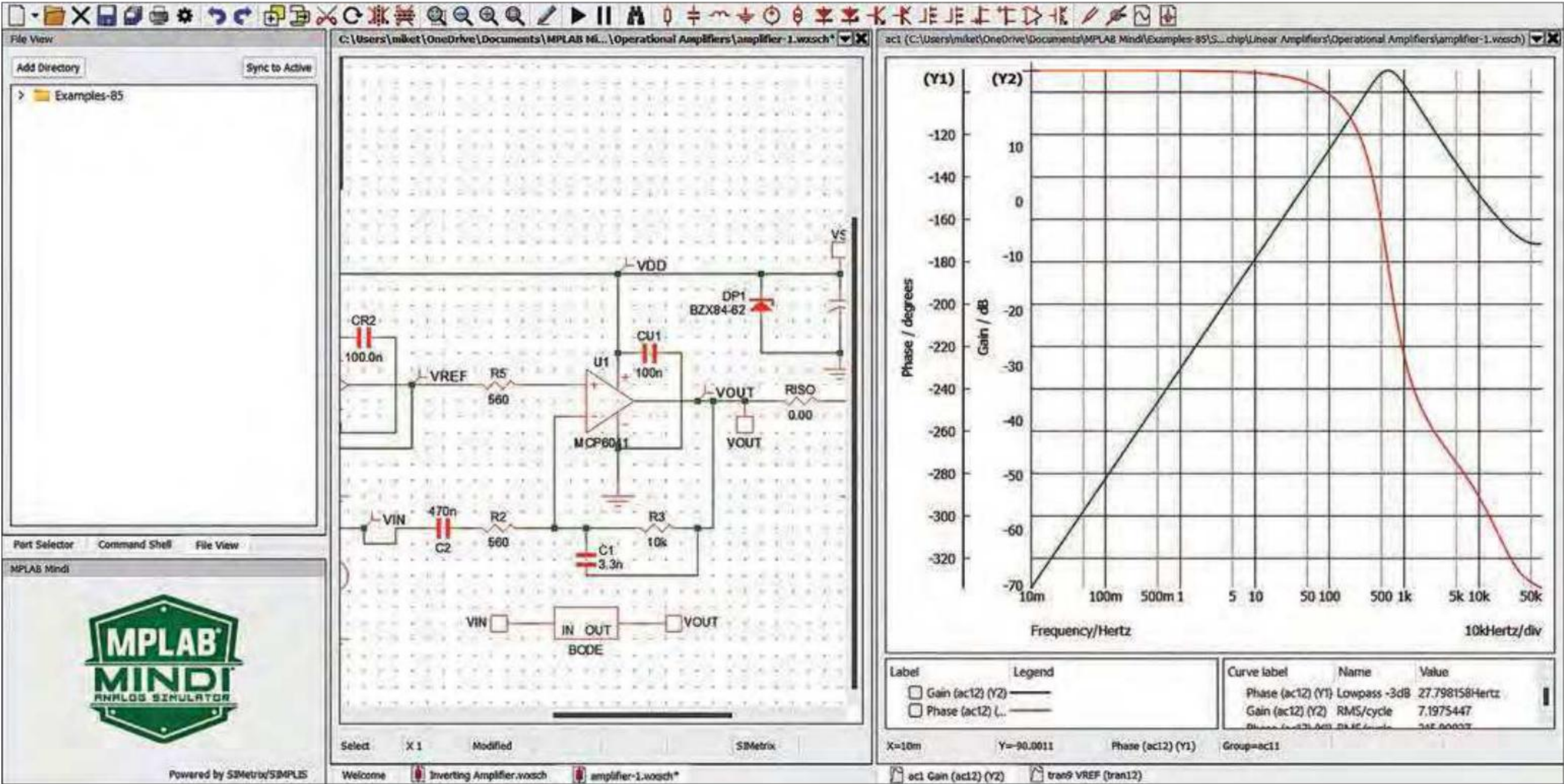


Fig.10.18. Using MPLAB MINDI.

voltage regulator like that shown in Fig.10.16(d). This circuit can provide an output of up to several hundred mA, so there's plenty of current available for any additional 5V circuitry.

Improving stability

Problems can sometimes arise when op amps are used in conjunction with capacitive loads. This problem can be alleviated by adding some additional stabilising resistance (R_{stab}) in series with the output, as shown in Fig.10.17. Depending on the reactive nature of the load (determined by the values of C_{load} and R_{load}) the value of R_{stab} should be typically between 2Ω and 10Ω.

MPLAB Mindi

Microchip, the manufacturer of the MCP600x family of chips provides Mindi, a handy design tool that will allow you to simulate and test a huge variety of op amp circuits. Mindi uses a SIMetrix/SIMPLIS simulation environment, with options to use SPICE or piecewise linear modelling to cover a wide range of simulation requirements. In addition to generic circuit devices, the simulation interface is paired with Microchip's proprietary model files. Mindi installs and runs locally on the user's own PC. Once downloaded, no further Internet connection is required, and the simulation run time

is independent of a remotely located server. As an example, Fig.10.18 shows Mindi being used to plot the frequency and phase response of the communication microphone preamplifier that we met earlier. The red and blue plots respectively show how phase shift and gain vary with frequency.

Going further

This section (below) details a variety of sources that will help you locate the component parts and further information that will enable you to get the best out of today's low-power op amps. It also provides links to relevant underpinning knowledge and manufacturers' datasheets.

Table 10.3. Going Further with Getting to grips with low-power operational amplifiers

Topic	Source	Notes
MCP600x datasheet	The MCP600x datasheet can be downloaded from: https://bit.ly/pe-oct22-mc1	Datasheets can also be found by following the links provided on various component supplier's websites
MCP6001, MCP6002, MCP6004	ICs can be obtained from several good component suppliers, including Farnell (https://uk.farnell.com), RS Components (https://uk.rs-online.com), and Mouser (www.mouser.com)	
Op amp circuit theory	Part 5 of <i>Electronics Teach-in 4</i> provides a general introduction to op amps (from Electron Publishing: https://bit.ly/pe-oct22-eti4).	The PE Direct Book Service at electronpublishing.com has several titles suitable for background reading on op amps and their uses.
MPLAB Mindi	A useful PDF introduction to Mindi is available from Microchip at: https://bit.ly/pe-oct22-mc2	MPLAB Mindi can be downloaded from: https://bit.ly/pe-oct22-mc3



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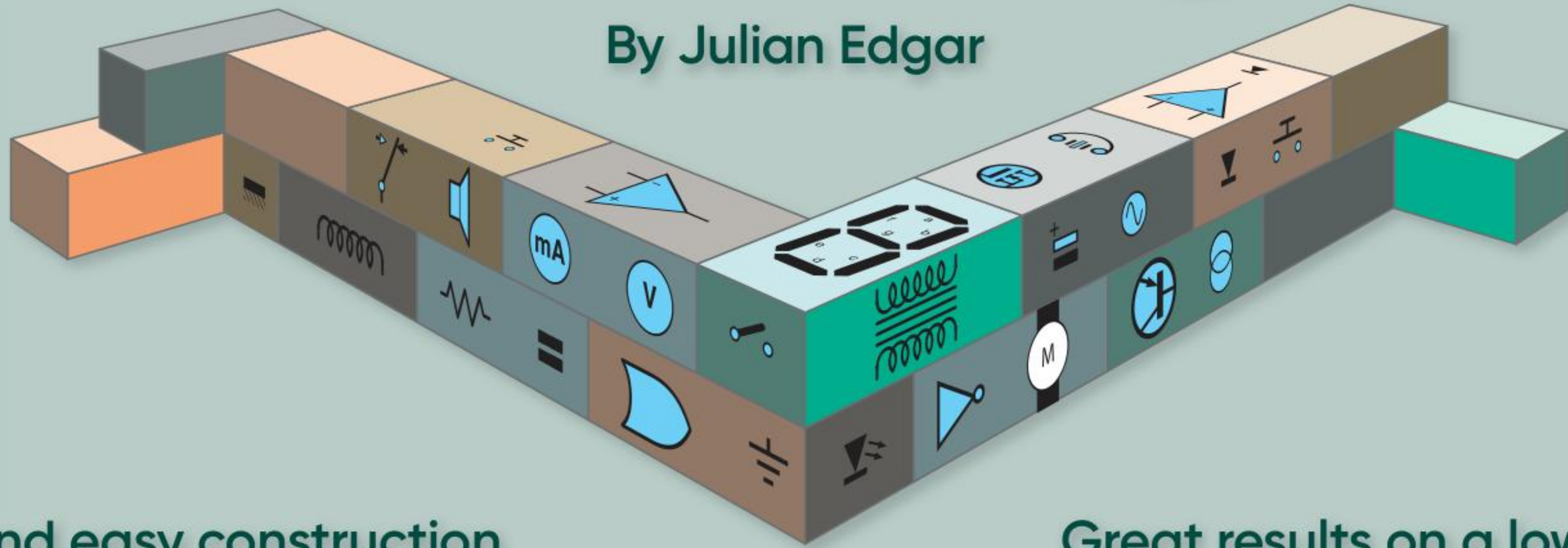


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Selecting and Using Actuators – Part 1

Turning electronic signals into physical movement – linear and rotary

Over recent issues we've covered simple and quick ways of controlling linear actuators and stepper motors and soon we will look at RC servos. But what we haven't covered is how to select these for different applications. Since that's a critical part of building any project that uses actuators, that's what we'll do in this article.

For our purposes, an actuator is any device that can turn an electronic signal into a physical movement of sufficient size and force to achieve the required mechanical task. That task might be to open a door or a cooling vent, move a model (or real) robot, oscillate a fairground attraction in a model railway layout, steer a solar reflector or PV panel – or even raise an aerodynamic air brake on an amateur racing car. In addition to linear actuators, stepper motors and RC servos, we can add to the list gearmotors and electrical solenoids. Let's take a look – it's a fascinating subject!

DC brushed motors

Permanent magnet, brushed DC motors are widely used in actuators. These motors are cheap and powerful for their size. In the type of actuators we're talking about, they vary from being smaller than your little finger to being perhaps as large as your fist (Fig.1).

DC motors of this type are relatively low in torque but high in speed. (See the breakout for more on power and torque.) Therefore, unless they are being used in low-torque applications like driving fans or rapidly spinning an off-centre weight (so creating a vibration alert), this type of motor is normally used in conjunction with gearing. Examples of geared DC motors include those used in RC servos, linear actuators and gearmotors (a gearmotor is a motor with a gearbox built onto one end).

Not widely used in hobby pursuits, but well worth considering if you want a very high-torque, low-speed output are car windscreen wiper motors (Fig.2). These use a worm-drive to give a huge speed reduction and so produce immense torque. And while we're on the topic of salvaging parts from cars: if you want to be able to control flow through a small duct, electronically controlled throttles are now available cheaply second-hand. These devices use geared DC motors and incorporate feedback pots (more on feedback in a moment).

Controlling DC motors

The great advantage of DC motors is that their speed is easy to control by simply varying the supply voltage (and so motor current). Pulse-width modulation (PWM), where a varying duty cycle square wave is used (duty cycle is the 'on' versus 'off' percentage of time), is highly effective at controlling motor speed. A typical PWM frequency for a small DC motor is 20kHz – that is, the supply is switched on and off 20,000 times per second. Of course, the motor cannot respond at this rate and so behaves as if it is seeing a lower average voltage – for example, a 50% duty cycle halves the effective supply voltage. Motor speed controllers (Fig.3) are cheap and widely available (they use a manual pot to control speed) or a MOSFET module can be duty-cycle controlled from a microcontroller to achieve automatic speed control.



Fig.1. Small 'hobby' brushed DC motors are widely available and cheap. They can also be salvaged from old tape recorders and toys. These motors are low-torque, high-speed designs and so unless they are driving a fan, they typically need to work through a reduction geartrain to give a usable output.



Fig.2. Car windscreen wiper motors use a DC motor and high-reduction worm-gear drive to give the output shaft immense torque. These motors are available cheaply both new and second-hand.

When the polarity of the power supply is reversed, DC brushed motors reverse in direction. Therefore, directional control can be achieved with a simple double pole, double throw (DPDT) switch or relay (Fig.4), or a microcontroller-controlled H-bridge.

Disadvantages of DC motors

And the downsides of DC brushed motors? Most small DC motors tend to have quite a limited life. They

generally used plain (bush) bearings that are not easy to lubricate. Also, the carbon brushes used to transfer power to the commutator wear away over time. (Precious metal leaves, sometimes used to replace carbon brushes, have even shorter lives). So, if you are thinking of an application where the motor is in constant operation, steer away from actuators that use brushed DC motors. On the other hand, many actuators are used



Fig.3. Variable duty cycle motor speed control module. This one is rated at 3A and costs under £2. It will work with an input voltage of 6 – 28V with speed control via a manual knob. It's ideal for varying the speed of brushed DC motors. These controllers are widely available – check eBay and Banggood.

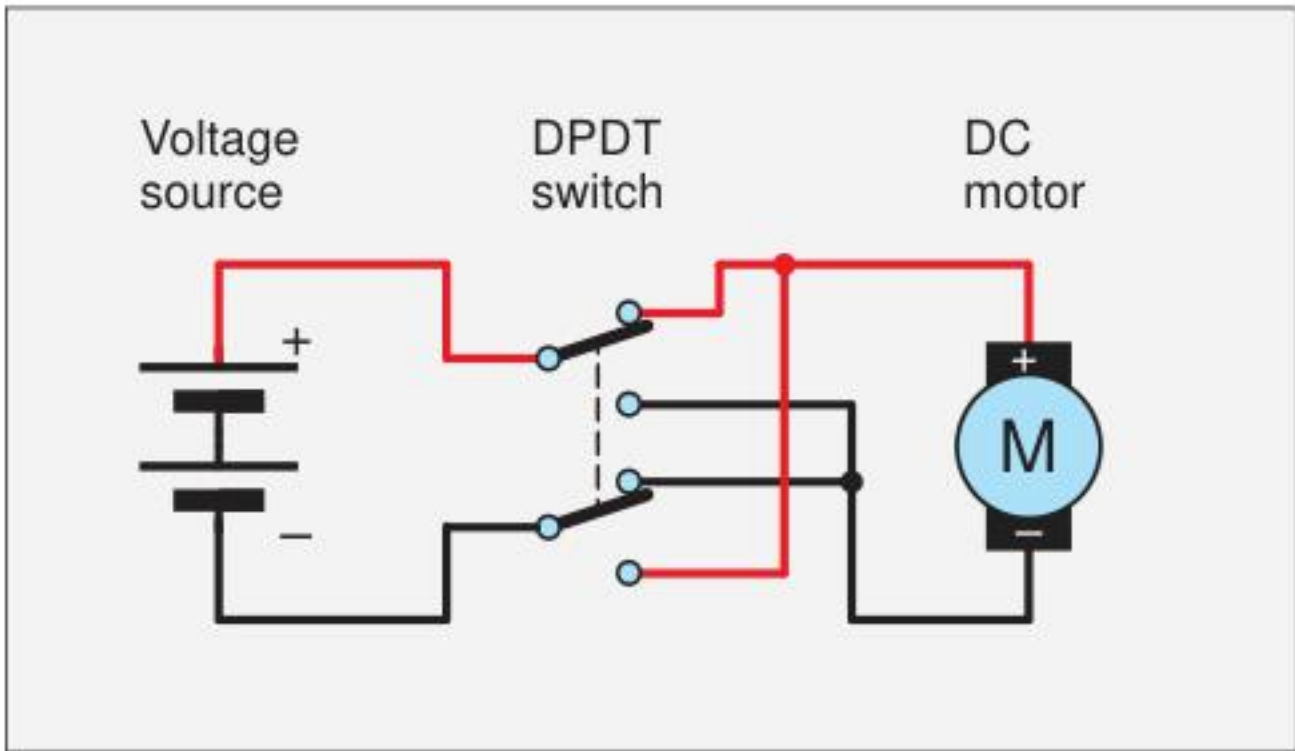


Fig.4. By using a double-pole, double-throw (DPDT) switch or relay, the direction of a DC motor is easily reversed.

Power and torque

Let's imagine that we want to open a heavy farm gate. When doing this manually, we go to the end of the gate furthest from the hinges and pull at right angles to the gate. We then 'walk' the gate through 90 degrees until it is fully open. Easy, huh?

But let's now replace the manual work of opening the gate with an automatic actuator, for example a motor-driven winch. We're going use one winch to open the gate and another to close it. Because we don't want to obstruct the road, the winch cables will connect nearer the hinge of the gate. If you've ever tried to open a gate pulling or pushing close to the hinge, you'll know it takes a lot of force, especially to get the gate moving.

So in this case, to pull in the cable, the winch will need to develop a lot of twisting force, which is called 'torque'. But does the gate need to move fast? Not really – it's not a problem if it takes (say) 30 seconds to open. That's good because it will reduce the power we need.

Let's look at that in more detail. To put it simply, power is the product of torque and speed. Therefore, as in the gate example, if we need high torque and low speed, the power demand won't be great. In this situation, we'd use a relatively low power motor teamed with a geartrain to multiply the torque (and so at the same time, slow the winch speed).

Another example of where we have a low power demand is where we need a high speed but a low torque. This might be the cooling fan in a piece of electrical equipment – the

speed is high, but the torque is low (it's easy to spin the fan), so requiring only low power – perhaps just a few watts for a small cooling fan.

But what about where you need high torque and high speed – and so a lot of power? For this very reason, you don't see this very often in actuators used in hobby electrical and electronic systems. However, one example might be a home-built electric bicycle climbing a hill. The speed needs to be sufficiently high that the bike doesn't fall over, and yet the torque must be great enough to propel the weight of the bike and rider up the hill. The resulting power may well be 300 or 400 watts.

So, a fundamental decision when selecting an actuator is to decide on the required power and torque:

Torque requirement	Speed requirement	Resulting power requirement
High torque	Low speed	Low power
Low torque	High speed	Low power
High torque	High speed	High power

Note that you don't need to quantify these values – that is, to actually measure the required torque and speed. (Well, you would if you were a professional engineer designing a system.) In our case, just having a feel for the required speed and torque – and so power – will stop us making gross errors in selecting actuators.



Fig.5. A linear actuator – when power is applied, the DC motor rotates, so turning a leadscrew and extending the actuator rod (top) from the body. This linear actuator incorporates potentiometer position feedback and costs about £75.

over their entire life for a total of only a few hours, so it very much depends on the intended application.

If heavily loaded or stalled, the current demand of a DC motor rises rapidly. This may overload the supply circuit or cause the motor itself to overheat and potentially burn out. Therefore, some type of overload safety cut-out is best used in situations where the motor may become overloaded. This safety cut can be as simple as a fuse or circuit breaker, or as sophisticated as current monitoring by measuring the voltage drop across a low value resistor in series with the actuator power supply.

Let's now look in more detail at three of the most common applications of DC motors – linear actuators, RC servos and then (next month) gearmotors.

Linear actuators

Where movement in a straight line is required, linear actuators (Fig.5) have major advantages over other actuators. They are easy to control for speed and direction of movement,



Fig.6. Mounts for linear actuators need to cater for some rotational movement. Light-duty mounts (left) are folded from sheet metal while heavy duty mounts (right) are cast or machined from solid. The mount pins fit through holes in the linear actuator's body and extending rod.

are available in a wide range of sizes, and develop a lot of force – albeit at low speed. This combination of force and speed means that they are relatively low-power devices, which is advantageous in terms of energy consumption and required current supply.

Inside a linear actuator is a DC motor that drives a reduction gear-train connected to a threaded rod – sometimes called a lead-screw. The rod normally uses a square-cut thread (like on a bench vice), and has an internally threaded nylon saddle (a nut) riding on it. The saddle is prevented from turning by a tab sliding within an enclosing tube and is connected to the extension rod. Therefore, when the motor is turning, the saddle slowly moves along the threaded rod, extending (or retracting) the rod. With the current switched off, the rod stays mechanically locked in position.

Limit switches are fitted at each end of the rod's travel. These automatically turn off the supply current when the rod is either fully extended or retracted. Reversing the polarity of the supply then causes the rod to move in the other direction. A two-position DPDT (or sprung centre-off) switch can then be used to control the extension of a linear actuator – the two-position switch causes the actuator to either fully extend or retract, and the sprung centre-off switch allowing the actuator to be manually positioned at points of less than full movement. (This is the approach already shown in Fig.4.)

Some linear actuators are fitted with a feedback pot. This type of linear actuator can be used in conjunction with an electronic controller, giving accurate positioning under different loads or with different motor supply voltages. The Pololu Jrk 21v3 USB Motor Controller uses feedback control and works well with linear actuators drawing up to 5A peak (higher currents

Position feedback

In many applications where we are using actuators, we need to have position feedback. For example, take a linear actuator. For a given actuator, the extension speed of the actuator's rod will depend on the supply voltage and load to which the actuator is subjected. Therefore, powering the actuator for (say) 3 seconds will not give a specified actuator position – the actuator position will vary over a range. Even a stepper motor, when stepped by a given number of pulses, may not end up in the designated position – it may have stalled under load, for example. Position feedback tells the controller where the actuator *actually is*, not where it is *supposed to be*.

This feedback information can be communicated to the controller in several ways, but an analogue voltage signal

from a potentiometer is often used. For example, an RC servo has an inbuilt pot-based position sensor and the servo's internal control electronics use its signal to help attain the specified output shaft rotation. Some linear actuators use an internal pot for position sensing, and this signal can be used by an external controller.

Where position feedback is being used, the controller typically makes use of a PID (proportional, integral, differential) control software approach. This allows the magnitude of the correction to be proportional to the size of the error, in addition to taking into account the rate of change of the error and when a small (but fixed) error exists. In practical use, a well set-up PID system will react quickly but without overshoot or jittering.

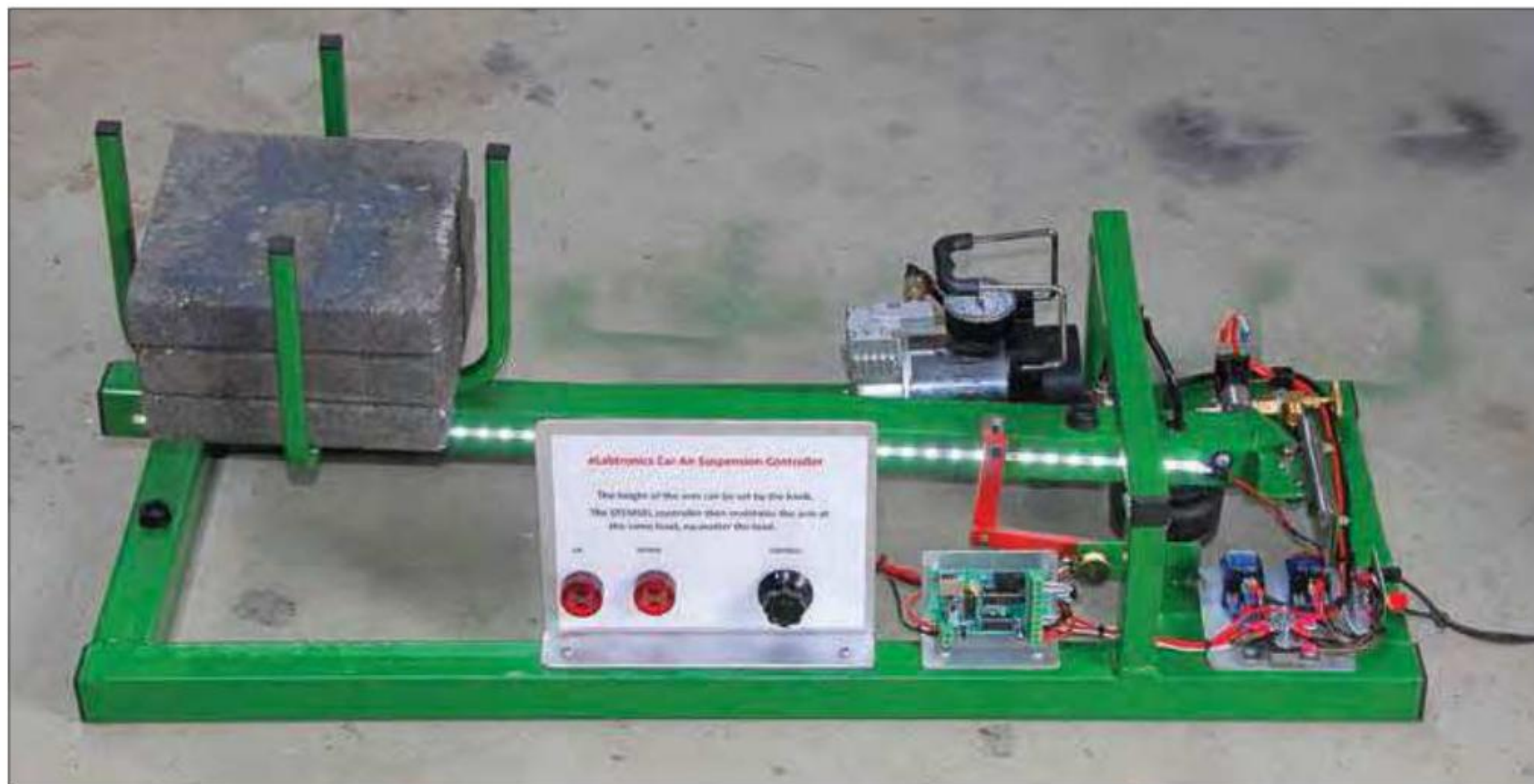


Fig.7. A demonstrator I built to show the action of a microcontroller (an eLabtronics Stemsell) controlling air suspension height in a car. An air compressor (rear) provides pressurised air via a solenoid valve to an air spring (the black bellows). The air spring supports a hinged lever laden with paving stones (left). Position feedback is given by a pot working through two linkages (the red arms). When a paving stone is removed, the load is reduced and the arm rises, with the controller then venting air from the spring to maintain the same level. Rotating the front control knob can vary the height of the arm by altering the air pressure in the spring. In a system like this, position feedback is critical.

are available in other Pololu controllers in the family).

Linear actuators – at least those priced at hobby levels – are not designed for constant movement. So, for example, it's better if controlling the orientation of a solar reflector or PV panel to move the actuator every hour, rather than every few seconds.

If you are moving large loads with a linear actuator, you will need to design a mechanical system that can cope with the high forces. For example, using a linear actuator to change the height of a desk – moving it from a sit-down

to a stand-up design – may involve quite large loads – especially if a child chooses to sit on the desk as it changes height! In this situation a strong frame will be needed.

Linear actuators have the following specifications:

- Low operating voltage (usually 12 or 24V DC)
- Current draw (minimum and maximum of around 1A and 7A)
- Maximum load (usually expressed in newtons – divide by 9.8 to get kilograms force)

- Speed (mm/sec, loaded and unloaded)
- Maximum duty cycle (eg, 10%, meaning that the actuator can operate for only 10% of the time)
- Maximum extension
- Physical dimensions

Linear actuators usually need swivel mounts at each end (Fig.6). This is because in most applications, one end of the actuator will move through an arc as the actuator extends. Swivel mounts are available in a variety of strengths, with light-duty ones made from folded sheet metal and heavy-duty units cast or machined from solid.

Linear actuators are more expensive than the other actuators described here, but for slow, powerful movement in a straight line, a linear actuator is the pick.

RC Servos

RC servos are especially suited for relatively small, low-power movements made with fine control. That makes perfect sense, because of course they were originally designed to move control surfaces in radio-controlled models boats and aircraft.

RC servos use an internal geared-down DC brushed motor. Most servos use plastic gears, but some are available with metal internal gears, with the metal gears being stronger. The internal step-down gear ratio is in the order of 100:1 (Fig.8). A splined output shaft is used and various levers and discs ('horns') can be fitted to this shaft. As quality (and so cost) increases, servos are more likely to be fitted with ball bearings (sometimes only on the output shaft) and have metal rather than plastic cases.

An RC servo is a 'smart' device – it contains control electronics. An internal pot is used as a position sensor, and the motor rotates until the shaft reaches the required angular position. This position is then held – if the shaft is mechanically rotated from its set position, it actively resists.

Servos use three connections – power (4.8-6V), ground and signal. The control signal comprises a pulse train with a varying pulse width 'on' time. The pulse width determines the servo's position, with 1.5ms corresponding to the servo's neutral point. That is, pulse widths shorter than 1.5ms cause the servo to rotate one way, and a pulse width longer than 1.5ms causes the servo to rotate the other way. The normal pulse width range is 1.0ms to 2.0ms. Servos can be controlled very accurately to attain precise angles.

A servo cannot be used without a specific controller – unlike DC motors and linear actuators, a servo will not



Fig.8. A micro RC servo. The transparent case of this unit allows you to see the DC motor, the reduction geartrain, feedback position pot and control circuit board. (Courtesy Wikipedia)

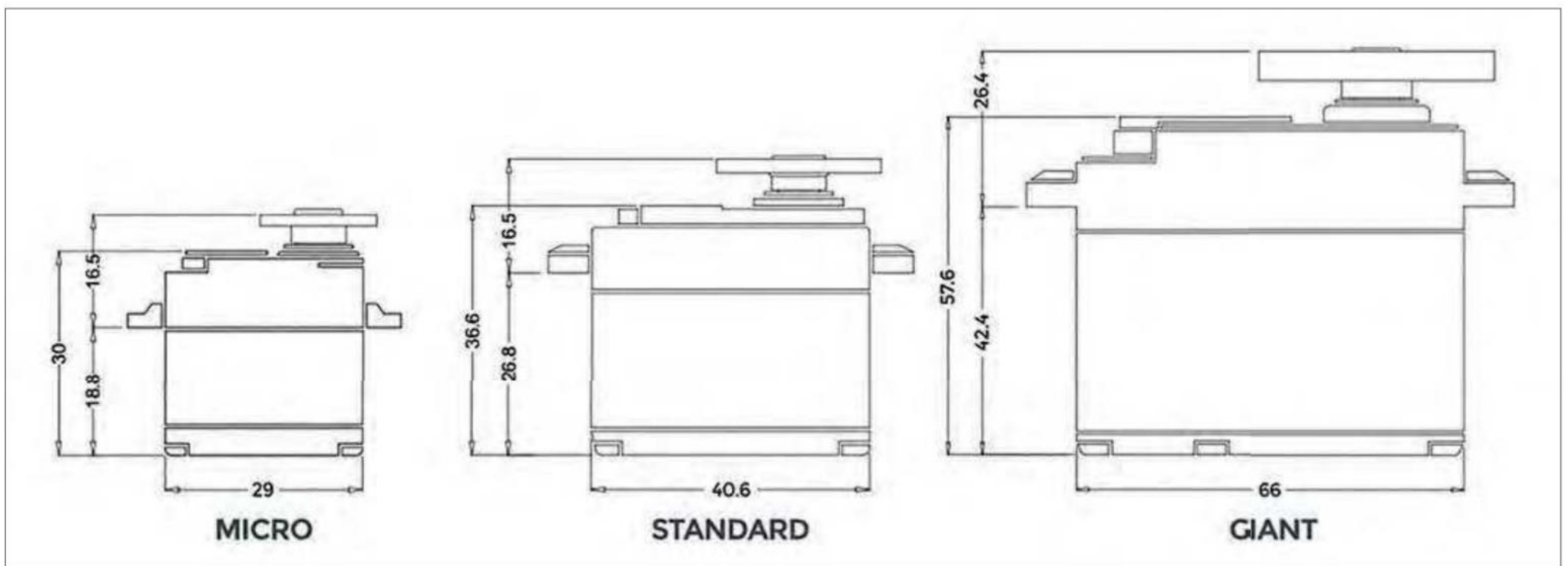


Fig.9. Servos are available in three sizes – micro, standard and giant. Dimensions are in mm. (Courtesy Sparkfun)

turn when simply connected to power. Dedicated servo controllers are available that can interface with manual controls like a pot or switch, or can work with a microcontroller. These controllers can also work many servos at once – a good example is the Pololu Micro Maestro controller and others in the Maestro family. Microcontrollers can also directly operate servos – remember, the controller doesn't have to handle the current requirement of the servo because the servo is fed power directly.

Servos are available in standard and continuous rotation forms. A standard servo has a movement range of 90° or 180°, while a continuous rotation servo, as the name suggests, continuously turns. In continuous rotation servos, the control is of only speed and direction. Servo specifications include:

- Torque
- Speed
- Size and weight
- Weatherproofness

Maximum torque and speed depend on the voltage with which the servo is being fed. As a result, these values are often specified for both 4.8V and 6V supply voltages.

Torque is specified in kg-cm (eg, 4kg-cm). To understand this specification, consider a servo with this torque rating that has been fitted with a 1cm long lever. If you connect the end of the lever to a spring balance positioned at right-angles to the lever, and operate the servo, the maximum 'pull' value the spring balance will show is 4kg. If you double the servo lever length to 2cm, the maximum pull value will drop to 2kg. (That is, the lever length in cm multiplied by the force value in kg will, for this servo, always equal 4.) Large servos can have a torque specification of over 35kg-cm.

Speed is normally specified in the time taken for the servo to rotate 60°. A typical

value is about 0.15 seconds, with a fast servo taking less than 0.1 seconds and a slow servo needing at least 0.25 seconds.

Servos are available in three sizes – called micro, standard and giant (Fig.9). Servos are available at ratings up to IP67 – that is, dustproof and protected against being submerged in one metre of water for 30 minutes. However, most low-cost servos are not weatherproof.

Curiously, servo current is not often specified but typical stall currents (that is, the maximum possible) are 1A for a standard servo, a few hundred milliamps for micro servos and as much as 10A for a giant servo.

Prices for RC servos vary over a very wide range. You can pay as little as £8 for a standard servo and up to as much

as £120 for a giant servo. Whatever the price, when using servos you need to remember that even in upscaled form, they are basically devices developed for use in toys and models. So, for example, even if the torque and speed figures of a servo indicate that one could be used for opening a gate or lifting a TV out of a piece of furniture, the life of the servo in those applications is likely to be quite short. On the other hand, moving the limbs on a small robot or animating items in a model railway layout are ideal uses for servos.

Next month

In Part 2, we will look at gear and stepper motors, in addition to exploring a simple way of switching off actuators at fully open and closed positions.



Fig.10. A servo with its normally supplied accessories. Shown are various 'horns' (attachments for the shaft), mounting grommets and collars, and mounting and horn attachment screws. To mount a servo, a rectangular hole is normally cut and the servo placed through the hole, its mounting tabs are bolted to the material around the hole via the grommets.



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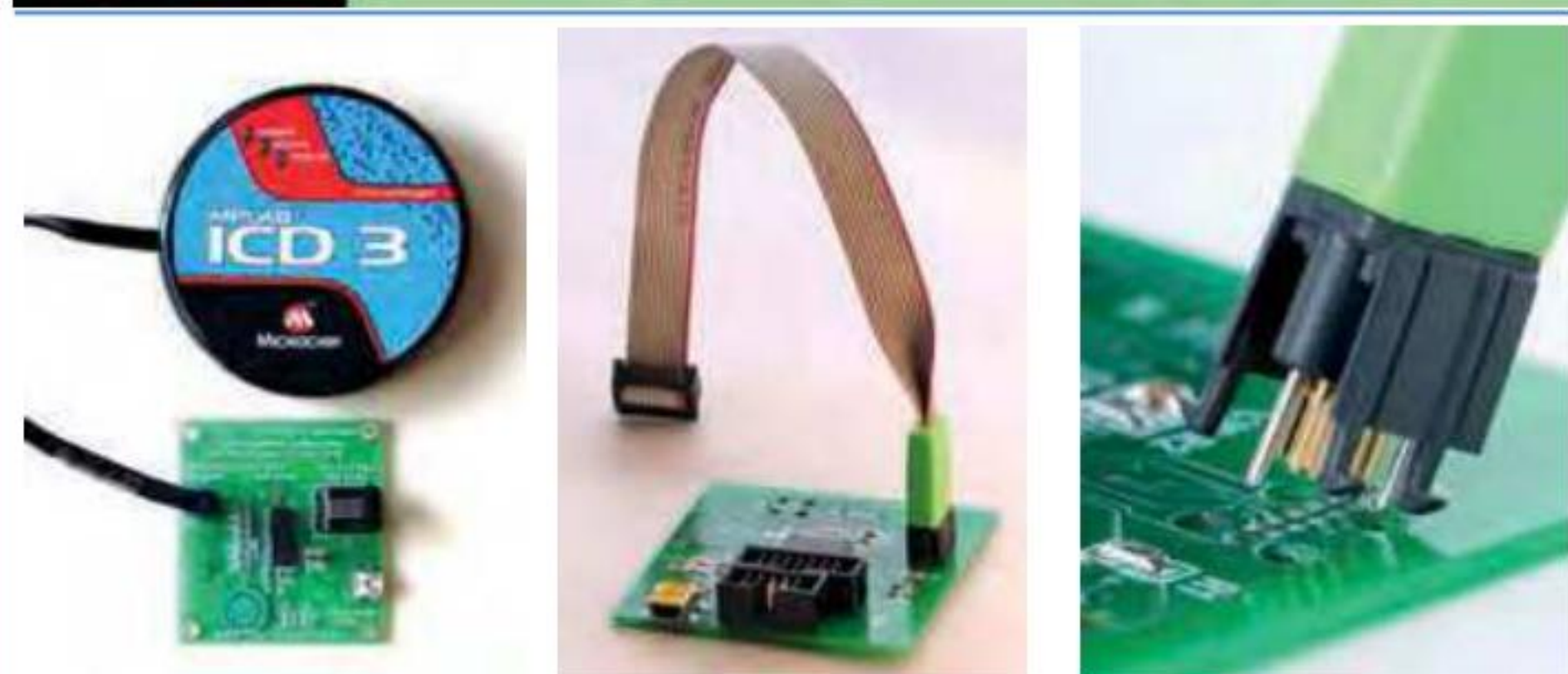
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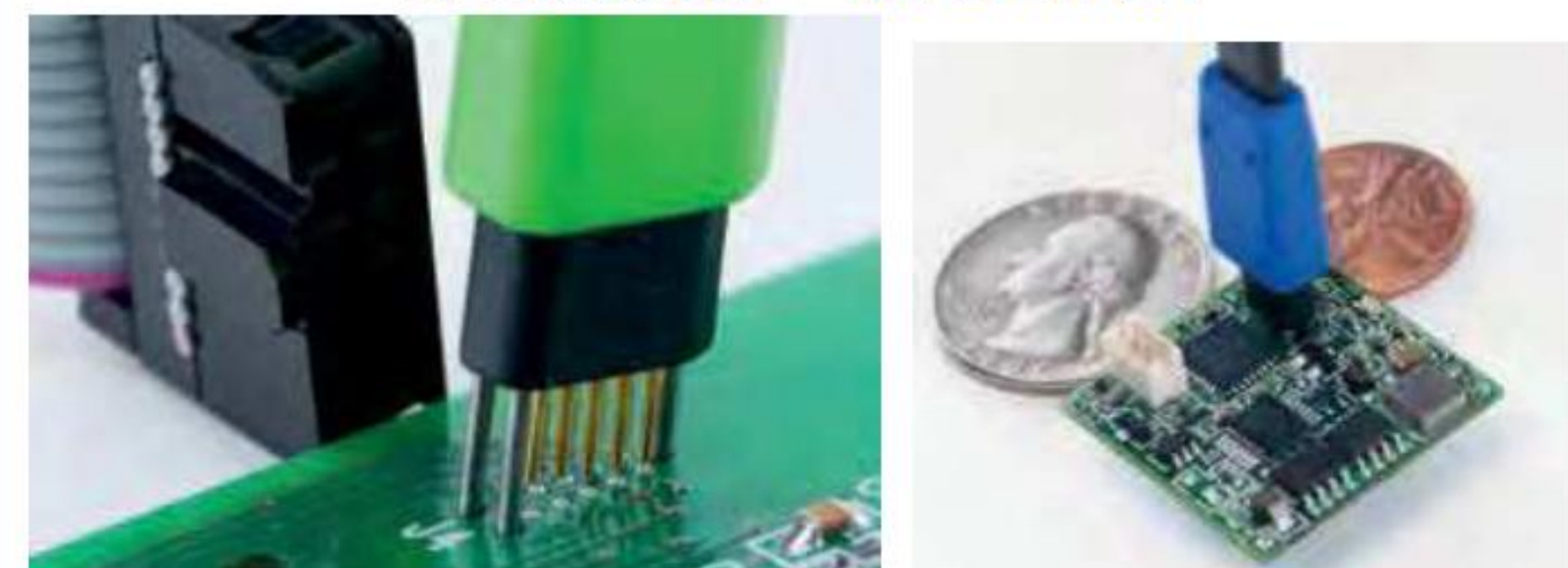


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JPG ELECTRONICS	72
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PEAK ELECTRONIC DESIGN	Cover (iv)
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Next Month – in the November issue

USB Cable Tester

It's frustrating when a USB device doesn't work, and you don't know if it's a problem with the device itself or the cable. Now there is an easy way to test all manner of USB cables using our USB Cable Tester. It's so handy, we think you will find it indispensable!

Model Railway Carriage Lights

It's nice to have carriage lights on a model train, to add to the realism. These model train carriage lights (designed for OO-gauge) are battery-powered and can be switched on and off with an external magnet.

Pocket Weather Station

Here is an excellent beginners' project that uses five modules to make something useful – a mini weather station you can carry everywhere with you.

Self-Contained 6GHz Digital Attenuator

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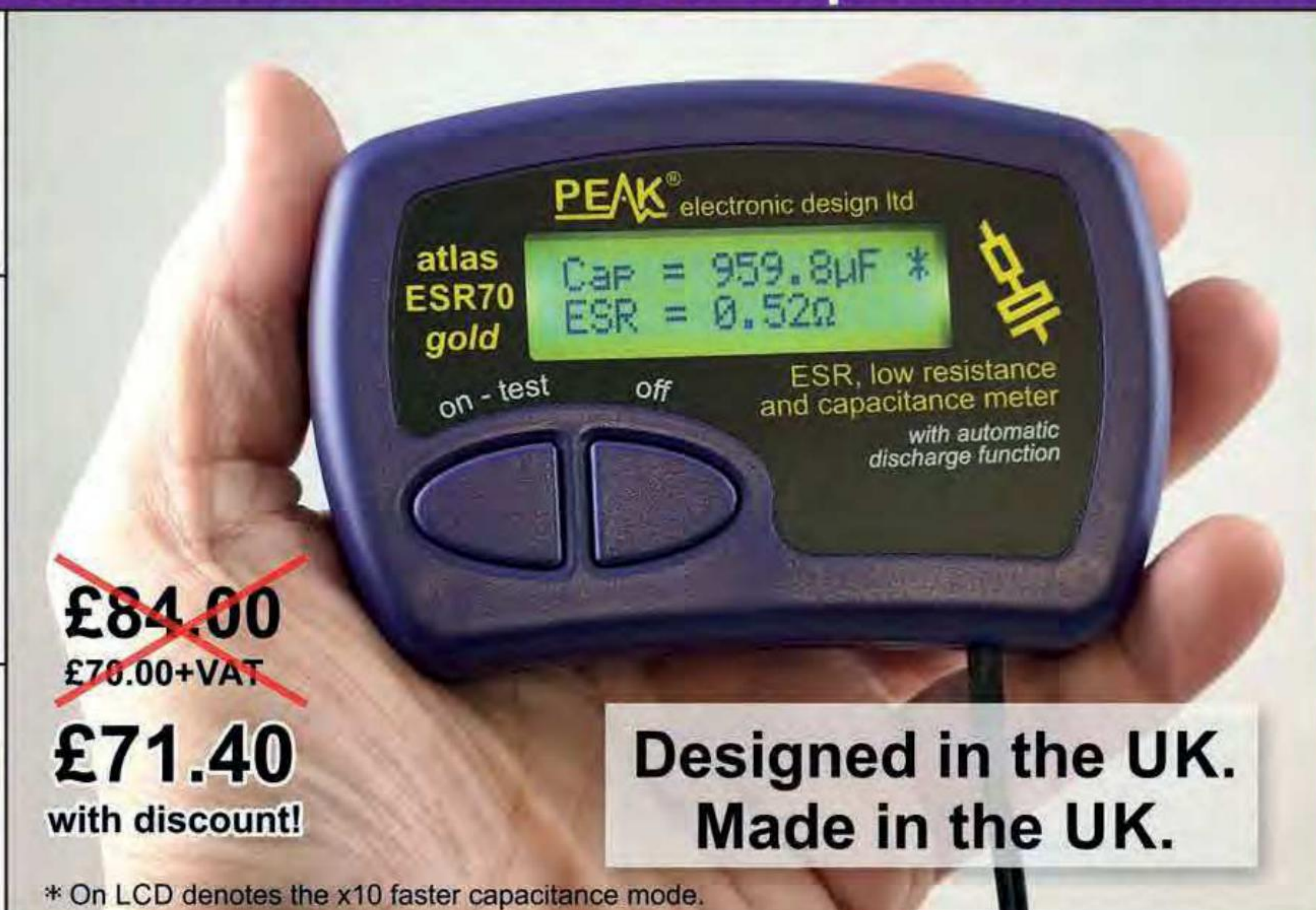
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